PENETRATION OF FREE-FALLING OBJECTS INTO DEEP-SEA SEDIMENTS

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THESIS

PENETRATION OF FREE-FALLING OBJECTS
INTO DEEP-SEA SEDIMENTS

by

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December 1971

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Penetration of Free-Falling Objects
Into Deep-sea Sediments

by

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ABSTRACT

A rational method is presented to predict the penetration of free-falling objects into deep-sea sediments by combining proven empirical theories from the field of soil mechanics with known hydrodynamic phenomena. The impact velocity of the object and the shear strength profile and density of the sediment are assumed to be known. The penetration problem was solved through the use of a computer by equating the work done during penetration to the energy of the object falling through air and impacting onto a modeled deep-sea sediment. The objects were simple geometric shapes ranging in weight from 500 to more than 1,000 pounds. The impact velocities ranged from zero to twenty feet-per-second. The results are compared with full scale tests and recommendations are made to extend the method to a water-sediment interface. The method successfully predicts the penetration of objects into weak, saturated, sediments within the accuracy of the state-of-the-art techniques for measuring the sediment mechanical properties. The impact duration time was observed to be relatively constant and independent of object velocity, shape, and weight implying that it may be a unique property of the dynamic behavior of a sediment type.

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I. INTRODUCTION

A. PURPOSE OF INVESTIGATION

Various types of objects will be lost which fall through the water column and impact on the ocean bottom as man continues to move more freely on the surface and through the oceans. Such objects can range from small and very expensive instrument packages to fleet submarines. It is important to know exactly how far they have penetrated into the bottom during search operations since complete penetration below the surface of the sediments may require a search by other than visual or acoustic methods.

The velocity and free fall attitude of an object that has been located and photographed on the bottom may be estimated from the penetration distance if the physical and mechanical properties of the sediment are known. The impact velocity and attitude could be potentially useful in reconstructing the event and also for determining the amount of energy transferred to the sediment and radiated from the point of impact.

The recovery method and force necessary to break a lost object free of the bottom during a salvage operation will depend to some degree upon how far the object has penetrated into the bottom sediments.

The fields of soil mechanics and foundation engineering have been concerned mainly with static situations including the prediction of the very slow settlement that a structure undergoes as it is erected. The weight is thus applied to

the soil in progressively greater amounts. Deep ocean bottom installations may be preassembled, floated to their site, and allowed to free-fall to a position on the bottom. The free-fall method of implantment is potentially useful for ocean structures since it decouples the structure from the influence of surface motion and tethering lines. Prediction of an accurate initial penetration depth upon contact, therefore, becomes a critical design factor.

An indication of the sediment's mechanical and physical properties can be obtained by observing probes of known physical configuration as they penetrate the bottom since penetration depth depends on sediment strength.

B. SCOPE OF INVESTIGATION

The purpose of this investigation was to develop a method to predict the penetration depth of objects dropped into a simulated deep-sea sediment. Experimental data was available to test and verify the analytical method that was developed. The full scale experiment employed large, heavy objects and it was necessary to let the objects fall through air to allow them to reach a velocity at impact equal to the highest expected terminal velocity of free-fall through sea water for very dense objects. In addition, dropping the objects in air eliminated free fall stability problems as the impact attitude was effectively controlled and the effects of angular momentum on the impact were minimized. The sediment used in the experiment was of re-worked continental origin characterized by low shear strength and high water content typical of deep-sea and pelagic deposits.

The initial boundaries and limitations that were imposed on the study were designed to simplify the complexities of the problem to permit the mechanics to be understood, and to retain the ultimate objective of practical application of the method at sea. The conditions are summarized below.

1. The impact velocity at the top of the sediment column was in the range from zero to 20 feet-per-second. Zero velocity at the top of the sediment column involved releasing the object at the sediment surface and its acceleration through the soft upper layers before coming to rest. The upper limit of 20 feet per second was believed to be a realistic terminal velocity in sea water for most objects.

2. Free fall was assumed, or gravity was the only downward force acting on the object.

3. The object shapes were limited to simple geometries with established hydrodynamic properties from theoretical calculations or empirical tests. Configurations designed to penetrate, such as a coring tool with a long barrel and large mass on one end were not considered.

4. The sediments were taken to be cohesive, with no angle of internal friction. They were also assumed to be low strength, less than four pounds per square inch, and to have high water contents typical of marine sediments.

5. The study did not include the effects of any settlement after initial penetration.

6. The minimum factors necessary to predict penetration depth were considered to be: the impact velocity; geometry and mass of the object; and the shear strength profile and density of the sediment.

C. HISTORICAL BACKGROUND

The loss of the U.S.S. THRESHER and the problems involved in the location of the hull which had penetrated deeply into very soft sediments served to emphasize the fact that little was known about physical phenomena associated with deep-sea sediments and the mechanism of penetration. This disaster prompted the original full scale experiments carried out by the Naval Civil Engineering Laboratory and used to verify the method developed in this study. The THRESHER disaster also pointed out the difficulties involved in sampling sediments at deep ocean water depths and using only a few samples tested in a laboratory to predict as precisely as possible the sediment's dynamic behavior in-situ. This study is only a step toward understanding all the variables and their relationship to each other.

The following is a review of the state-of-knowledge before the investigation and the technical background. The variables involved and the development of other penetration equations are discussed.

1. State-of-Knowledge

The problem of earth penetration by projectiles is a classical one of terminal ballistics and an immense amount of both theoretical and experimental literature exists on the subject. Empirical attempts to determine the thickness of earth embankments needed to protect soldiers were made as early as 1742 [Young, 1969]. In recent years the free-fall penetration problem has been studied to provide protection

against artillery, to estimate forces acting on a structure during earth impact such as would be required by orbiting nuclear power plants that would have to remain intact during re-entry and landing on earth, and to determine physical soil properties remotely by an acceleration-time record transmitted from a projectile penetrometer. The studies have involved the fields of engineering, mechanics, fluid mechanics, geology, soil mechanics, aerodynamics, wave propagation, as well as other disciplines. They were concerned with the problem of a body falling with high velocity through air and impacting on hard continental soils. Bibliographies of prior investigations are available [Schmid, 1969 and Young, 1969]. Dynamic studies in the field of soil mechanics on land are still in their infancy. Whether they can be extended to structures and the penetration problems in the deep oceans probably will remain a question for some time into the future for four basic reasons.

First, the velocity of an object free-falling through water will be much less than the velocity of a similar object in air. At very low velocities, from zero to 10 feet per second, the inertia of the object may not be important compared to other factors. In water the added mass of entrained fluid must be accounted for, but probably would be ignored in air.

Second, continental soils are quite different from deep-sea sediments. Sediments in the ocean basins typically have very small grain sizes, often clay sizes of .005 mm and

smaller. The rate of sedimentation is measured fractions of millimeters per year with very old layered material found relatively close to the top of the sediment column. Deep-sea sediments are completely saturated with interstititial pore water often accounting for half their bulk volume. The pore water is not the pure water commonly found on land, but the chemically complicated sea water which causes flocculation of some sediment particles and the presence of authigenic minerals near the sea-sediment interface. Lower in the sediment column, diagensis and cementation between particles occur forming a loose fabric often with the porosity being relatively constant with depth. The effects of the low 2 degree centigrade temperature and high 6,000 pounds-per-square-inch pressure encountered at the median ocean depth create an entirely different environment than found on the continents. The degree of reworking by benthic organisms may also be important in determining the mechanical characteristics of the upper layers of the sediments.

Third, when measuring the mechanical properties of the sediments, the amount of disturbance that the sample undergoes as a result of the sampling process, handling and preparation for testing, temperature and pressure changes, and organic growth or decomposition is difficult to precisely estimate and may vary from one sampling and testing technique to another [Richards, 1961].

Fourth, if the sediments in the upper layers are treated as a suspension of particles in a fluid, which may

be a valid approach to sediment dynamics if the water content is over 100 percent, then another problem arises. The fluid dynamics of non-newtonian materials have been researched for conduit flows such as slurries in pipelines, but very few investigations of external flow about a body [Pazwash and Robertson, 1969], and unsteady flow at a boundary have been made.

2. Prior Investigations

There are only a few records of objects that have been lost and recovered. The instances where things have been recovered or photographed to document and determine the penetration depth together with adequate data about the mechanical properties of the sediment are virtually nonexistent. The same lack of data exists in reports written about the few cases where penetration was investigated. The reports typically set forth equations with empirical constants and contain no information about the controlling sediment parameters.

Much literature and empirical information is available about pile driving. The forcing of a long piling into soft sediments is, however, quite different from the free-fall penetration problem.

D. TECHNICAL BACKGROUND

All of the variables were studied, then the development of the previous penetration equations was researched before an attempt was made to solve the penetration problem. A review of the known variables for which data exists was made

to develop a method that would be of use at the present time using available data and techniques.

1. The Variables Involved

Penetration may be a function of more than 20 different variables and may be described by the following equation:

$$f\,(V_o, M, A, z, e, r, S, E, \nu, \rho_s, T, \phi, w, s, \xi, \mu_w, \mu_s, c, k, \gamma, \delta, \rho_w, a_s, h) = 0 \tag{1}$$

where,

V_o = impact velocity

M = mass of the object

A = cross sectional area of the object

z = depth of penetration

r = surface roughness of the object

S = object shape

e = void ratio of the sediment

E = Young's modulus of the sediment

ν = Poisson's ratio of the sediment

ρ_s = density of the sediment

T = time for penetration to occur

ϕ = mineralogic and chemical composition of the sediment

μ_s = viscosity of the sediment

c = shear strength of the sediment

k = permeability of the sediment

s = sensitivity of the sediment

w = water content of the sediment

γ = dilation of the sediment

δ = grain size of the sediment

ξ = post depositional changes of the sediment

ρ_w = density of the water

μ_w = viscosity of the water

h = water depth

a_s = adhesion of the sediment to the object

Such a list is self explanatory and is not exclusive. Some of the above properties are related to others, and the parameters may thus be reduced in number by a dimensional analysis [Liu, 1969]. Some of the properties, however, are not amenable to a mathematical analysis, for example the grain size distribution and the grain's morphology and orientation in the sediment fabric. A phenomological approach to the problem may, therefore, be required [Muga, 1966]. To put all of the variables into a system of equations may be an impossible task, and for this reason the prediction of penetration into deep-sea sediments may remain somewhat of an art and not susceptible to an exact solution for some years.

The deep-sea sediment particles accumulated over millions of years occur in many types which reflect unique depositional conditions of the earth's history. The mechanical properties vary widely, as subsequent to deposition the sediments may have undergone secondary cementation, diagenesis, recrystallization, and a degree of reworking by animals in the top important layers [Smith, 1969]. Some problems involved in learning more about deep-sea sediments are set forth in the following paragraphs.

The details of the sea-sediment interface and upper sediment layers in the depths of the ocean are only grossly known the world over. In the most studied ocean, the North Atlantic, Keller [1967], estimates one core has been analyzed for sediment mechanical properties for every 30,000 square miles of ocean floor. Less data is available in the Pacific. The variation of the ocean bottom's nature and the high cost of about 1,000 dollars per foot of core recovery and analysis will limit any great expansion of knowledge.

Much input to the design of foundations on land is based on past local experience incorporated into local building codes. On land, tests can be conducted and equations developed that fit special circumstances in certain areas at considerably less expense than in the oceans. Also a past history exists for land areas of interest, whereas comparatively little has been known of deep-sea sediments until very recent times. Although the horizontal area variability of deep-sea sediments may be less than that of continental sediments, to empirically categorize the seventy percent of the earth's surface covered by water and anticipate a return in less than the number of years that have elapsed since structures have been built on land would be folly.

2. The Development of Previous Penetration Equations

A review of the development of penetration equations emphasizes the importance of the various constants that act to control the penetration depth. The discussion that follows combines the outlines given by Schmid [1969], and

Young [1969]. First and most basic from Newton's second law,

$$F(t) = M\ddot{x}(t) \tag{2}$$

it can be shown that penetration depth is determined if velocity is known as a function of time. In general this is not the case for unsteady motion at a boundary.

Other classical equations are also based on Newton's second law where resistance to penetration is a function of the instantaneous velocity, V;

$$-M\ddot{x} = C_1 + f_1\ (V) + f_2\ (V^2) + \ldots f_n\ (V^n) \tag{3}$$

which postulates that during the first phase of penetration, at high velocity, the motion is governed by resistive forces proportional to velocity to some power, and at the final stages of penetration the resistance is independent of velocity. If the functions, f_1, f_2, $\cdots$ f_n, are taken to be constants and the highest power of n assumed to be 2, then equation (3) simplifies to;

$$-M\ddot{x} = \alpha + \beta V + \gamma V^2 \tag{4}$$

where at high velocities the forces controlling penetration are proportional to V^2 or analogous to drag force in fluid flow. At moderate velocities resistance will be proportional to the first power of V, analogous to viscous resistance, and at the last stage, proportional to a constant force independent of velocity. According to how the constants in equation (4) are treated, the following classical equations can be derived after integrating twice with the initial conditions,

$V = V_o$ at $t = o$, and final conditions, $V = o$ at $t = T$.

Robins-Euler $z = \frac{M V_o^2}{2 \alpha}$ (constant resisting force) (5)

Poncelet $z = \frac{M}{2 \gamma} \ln \left(1 + \frac{\gamma V_o^2}{\alpha}\right)$ (resisting forces constant and similar to fluid drag) (6)

Resal $z = \frac{M}{\gamma} \ln \left(1 + \frac{\gamma V_o}{\alpha}\right)^2$ (resisting forces similar to fluid viscosity and fluid drag) (7)

The question relative to the use of the above equations rests with the constants, α, β, γ, which are determined by the geometry and mass of the object and the type of medium being penetrated. Schmid [1969] discussed several empirical penetration equations from the literature which are variations of the above classical equations. The constants were determined from high velocity impacts on continental soils.

Thomason and others [1968] used Poncelet's equation to determine the amount of charge required for an explosive anchor system.

$$z = \frac{p}{2\ gib} \ln \left(1 + \frac{b}{a} V_o^2\right) \tag{8}$$

where

$p = \frac{W}{A} = \frac{\text{weight of projectile}}{\text{normal frontal area}}$

a = constant related to the shatter strength of the medium (for "mud" a = 320 psi)

b = an inertial coefficient for the material

i = a form factor, usually 1.0

Evaluation of a and b is a problem and unfortunately a comparison of predicted and actual penetration was not given. However, the penetration depth's dependence on high velocity was illustrated.

Young [1969] presented a semi-empirical solution to the penetration problem derived from 160 full scale tests on continental soils with impact velocities ranging from 100 to 1,000 feet-per-second. Penetration was treated as three phases: (1) impact, (2) moving through the soil, and (3) coming to rest. The phenomena of entry is not the same as moving through the soil, but the surface effect of entry was found to be negligible after the object had penetrated three body diameters. The basic form of Young's equation was:

$$z = f_1 (S) \, f_2 (A) \, f_3 (W) \, f_4 (V_o) \, f_5 (N) \tag{9}$$

where

S = a shape parameter of the object

A = cross sectional area of the object

W = weight of the object

V_o = impact velocity

N = constant dependent on soil properties averaged over penetration distance

Two equations were determined for two ranges of velocity, one for less than 200 feet per second and one for greater than 200 feet per second. The low velocity equation was:

$$z = 0.53 (N) (S) \left(\frac{W}{A}\right) \ln \left(1 + 2 \times 10^{-5} V_o^2\right) \tag{10}$$

and nomograms were given for easy solution. All Young's data fitted within ± 20% deviation. Again it should be noted that

the soil property constant, N, could vary by a factor from 1 to 50 and "was arbitrarily assigned by those knowledgeable in the field".

If penetration is treated as being resisted by viscous forces only, the following results according to Schmid [1969];

$$M\ddot{x} = A\,V(t) \tag{11}$$

which has as its solution

$$x = \frac{V_o}{\alpha}\left(1 - e^{-\alpha t}\right) \tag{12}$$

where

$$\alpha = \frac{A\mu}{M} \tag{13}$$

When t goes to infinity, the maximum penetration becomes:

$$z = \frac{V_o}{\alpha} \tag{14}$$

but again resolving the viscous parameter of the sediment, μ, and establishing a realistic time, t, become difficult.

Soils do not behave as isotropic, linearly elastic materials, except possibly at very small strains [D'Appolonia and Lambe, 1970]. Penetration into a material causes the elastic limit of the material to be exceeded and theories of elasticity cannot be applied directly to the problem. Theories of elasticity and plasticity applied to problems of deformation assume idealized stress strain laws which are not well suited to soils and more basically ignore the important dimension of time, and assume that the state of strain is instantaneous.

Various viscoelastic models, Figure 1, with combinations of Kelvin and Maxwell models, of a sediment can be

assembled and solved by Laplace or Fourier transforms, if time dependence is linear.

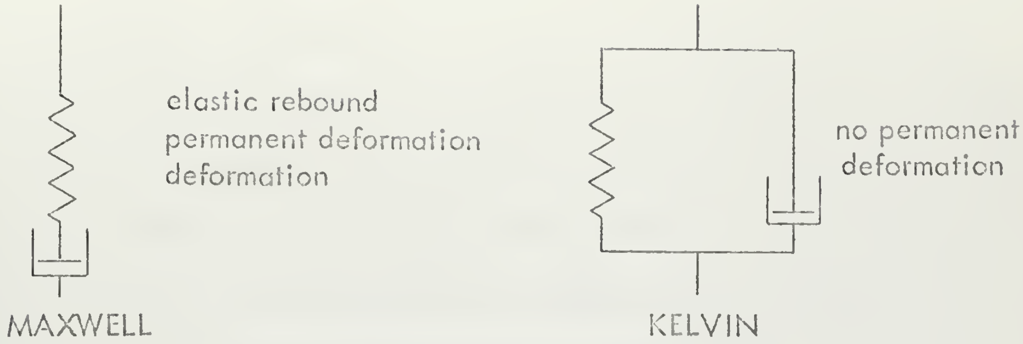

Figure I. KELVIN AND MAXWELL VISCOELASTIC MODELS

However the problem of determining the necessary soil parameters is non-trivial, and to get a unique solution, several sets of parameters are required [Schmid, 1966].

Modern advances in rheology and the continued development of the finite element method with appropriate yield criteria such as developed by Noh and Wilkins in 1964, and outlined by Schmid [1969], and the analysis of the initial settlement problem by D'Appolonia and Lambe, [1970], may be useful but again the problem of relating all parameters and determining the stress-strain behavior and yield criteria of a rheologically complicated material such as deep-sea sediments, may remain elusive for the near future.

In very weak, high water content, deep-ocean sediments, the penetration problem is somewhat similar to the problem of ship slamming. Studies of ship slamming and unsteady hydrodynamic impacts at a water surface have mainly been concerned with peak pressure, velocity-time relationships as a function of the form of a structure as it penetrates

a fluid boundary and not penetration depth. Extensive literature and model test records exist [Ochi, 1962].

A method to estimate the impact velocity from the observed penetration depth was developed by Mandl and Givens [1964] after an aircraft was lost and crashed into soft clays in northern Canada. The method developed and explicity solved an equation of motion for a sphere and cylinder penetrating at high velocities into a Leda clay

$$-(m' + M)\ddot{x} = Mg - F - D \tag{15}$$

where

F = the static strength of the clay, a function of penetration depth only

D = a drag force considered a function of penetration depth, velocity and time

Experimental tests of high velocity impacts into clay, (greater than 800 feet per second) confirmed that the method overpredicted penetration depth. The over-prediction was expected since viscous dissipation and elastic wave initiation were ignored.

After a detailed examination of mathematical methods available for analysis of unsteady motions of an object crossing an air-water interface, Moran [1965], concluded that none of them could yield a uniformly valid approximation to the solution of surface crossing and that the best hope for obtaining a reliable estimate was with numerical analysis.

3. Known Variables for Which Data Exists

Since all of the methods reviewed rely totally on the ability of the selected variables and constants to correctly

parameterize the penetration problem, it was necessary to review what is known about the variables. The physical properties of the object are assumed to be known but the description of the sediment strength is subject to the interpretation of empirical tests or, in some instances, phenomenological observations. Even though deep-sea sediments are very different from continental soils, a review of what has been learned about the mechanical behavior of fine-grained clays on land and what is known about deep-sea sediments is necessary to assemble a workable solution. Also the problems of sampling and testing at sea cannot be ignored.

Information about the following parameters; density, water content, void ratio, shear strength, and sensitivity, which describe the mechanical behavior of deep-sea sediments, either exist in the literature or may be easily determined through laboratory tests which have been standarized and soon may be routinely performed at sea on oceanographic vessels.

The bulk density of deep-sea sediments is determined from routine measurement of the weight of a known volume of sediment. Typical values range from 74 to 125 pounds per cubic foot with the most common sediments in the range from 78 to 109 pounds per cubic foot [Keller, 1967]. The bulk densities of North Pacific sediments are generally lower than those of the North Atlantic.

The void ratio and porosity are a measure of the volume of sediment in a sample compared to the volume of

voids, which are filled with sea water in the case of deep-sea sediments. They are also a measure of particle point to point contacts and bonds [Schmid, 1969]. The measurement is easily made with a pycnometer that measures that volume of a known weight of oven-dried sediment.

Sensitivity, the ratio of the original undisturbed shear strength to a remolded and disturbed shear strength, is important to the penetration problem since the object moves through disturbed sediment during penetration. Its importance is hard to estimate since most samples are disturbed to some degree. Mitchell and Houston [1969] indicate that in the range of sensitivity from 1 to 8, typical of deep-sea sediments, the mechanism that causes sensitivity is chemical cementation, which is not well understood by soil mechanists but obviously important.

For a cohesive sediment, the strength is a measure of the sediment's ability to resist mechanical deformation. Large masses of cohesive soils generally fail along a surface and hence the strength of a cohesive soil is defined as shear strength. For purely cohesive sediments undergoing large deformations, particle to particle interactions which would cause an "angle of internal friction" and increase in the strength of the sediment are generally assumed not to exist. However, as more sophisticated testing techniques are developed, this may prove to be an erroneous assumption.

Typical values of shear strengths were given by Keller [1967] to range from .25 to 2.5 pounds-per-square-inch, with

the most common range between .5 and 1.5 pounds-per-square-inch. The North Atlantic basin sediments have slightly higher strengths than the North Pacific. The presence of carbonates will increase shear strength, but few carbonates are found below 12,000 feet. In the Gulf of Mexico, Bryant and others [1967], found shear strengths of silty clay turbidites of the abyssal plains to range from .3 to 1.1 pounds-per-square-inch with the pelagic sediments of the continental slopes having strengths up to 5.9 pounds-per-square-inch.

Richards [1967] predicted that a reduction of in-situ strength would be caused by sampling and laboratory testing and that the reduction might be proportional to the grain size, the amount of gases in solution, and temperature increases that cause increased bacterial action. However, samples tested in-situ at 300 meters with a vane device correlated well with tests from cores taken from the same area a year earlier and tested with a fall cone and laboratory vane [Richards, 1967]. Recent experience indicates this may have been an isolated instance of agreement.

Laboratory tests to determine the effects of temperature and pressure on shear strength and consolidation have been carried out with greatly disturbed, remolded samples [Vey and Nelson, 1966]. The results were somewhat inconclusive due to the small number of samples and difficulties in instrumentation. The results indicated that there was a decrease in direct shear strength with increased environmental

pressure for a fine grained sediment with high void ratio. The vane shear tests with increased environmental pressure showed an increase in shear strength for plastic sediments and a dec

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ting. This precludes the use of an unconfined compression test or any test that requires trimming the sample before testing. The vane shear and fall cone tests can be done on a sample in its original container and the vane shear has the added advantage of easy adaptation to in-situ testing. Kravitz [1970] compared the results of Wykham-Farrance vane, Torvane, and fall cone tests on weak sediments and found that the results

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from the fall cone were more repeatable than the Wykham-Farrance vane or the Torvane which showed least repeatability. These results may have been expected since an important factor in vane shear testing is the rate of loading and the separation of static and dynamic resistance [Housel, 1959].

The vane test's advantages are: First, it can be conducted in-situ and a strength-depth profile is easily obtained where all other methods require reentry of a hole, which may be very difficult in the deep ocean, or discrete sampling which disturbs the sediments. Second, it is a simple inexpensive technique when compared to sampling and laboratory testing. Third, it does not require a system of weights or free-falling objects to cause the soil to fail and therefore has the potential to be used at sea on a rolling, pitching ship.

The vane test limitations can be summarized as: First, it can only be used in uniform, saturated, cohesive sediment. Second, when done in-situ it does not obtain a sample for evaluation. Third, it imposes a failure surface which may not be the weakest surface or relevant to the problem being studied.

Eden [1966] found that the vane will yield higher strengths with more consistent results in sensitive clay with shear strengths less than ten pounds per square inch when compared to a fall cone. This is in conflict with the more recent tests of Kravitz and emphasizes the problems in testing. Kravitz made statistically significant tests on a

laboratory prepared montmorillonite sample and Eden tested natural clays.

Shear strength values from a vane were found to be 15% higher than those obtained by an unconfined compression test on Gulf of Mexico slope sediments [Morelock, 1969]. This may be partially balanced by the findings of Inderbitzen [1970] who found that laboratory vane measurements were 22% lower than in-situ measurements made from DEEP QUEST at a depth of 3,500 feet. This is in rough agreement with the estimation made by Crisp [1968], of a decrease in shear strength due to an expansion of pore water caused by temperature and pressure changes. Crisp estimated that an expansion of pore water by two percent would occur by raising a sample from 12,000 feet deep and 2 degree centigrade temperature to surface temperature and pressure. This expansion could significantly alter the strength properties of a sediment and Crisp showed shear strength should decrease 10 to 15 percent.

The in-situ tests conducted by Inderbitzen showed a uniform increase in strength with depth in the sediment, but the laboratory tests were erratic, suggesting that the difference may have been caused by disturbance during sampling and preparation for testing.

Penetrometers offer the great advantage of potentially being self-contained instruments. They either record or transmit a force versus time curve from which depth of penetration by integration and soil properties can be

inferred. In order to extrapolate to different shapes and velocities, however, the curve's shape must be a characteristic of the sediment parameters. There are real problems with instrumentation and directional stabilization as the penetrometer penetrates since centric impact rarely occurs with other than symmetrical objects [Schmid, 1966]. Three other problems also complicate the penetrometer approach to determining sediment properties in the oceans. First, to get deep information, the penetrometer must have enough energy to penetrate, and at low terminal velocities in water it will probably require a smooth, known, driving force. Second, viscous forces may predominate on small penetrometers making extrapolation to larger objects very difficult. Third, penetrometers do not retrieve samples for analysis of other sediment parameters.

Acoustic sounding and seismic methods do not discriminate enough of the structure of the upper layers of sediments important to the penetration problem to allow their use at the present time. In the future the use of high frequency pulsed sources mounted on deep vehicles, hold promise for better resolution of the upper layers.

The methods of determining sediment strength that have been discussed were developed for use in classical foundation engineering where a safety factor based on engineering judgement would be applied to the final result. The penetration problem is quite different as it requires an exact answer since an error factor of two could mean the

difference between an object being completely buried below the surface or having one half of the object exposed and easily located.

II. METHOD OF ANALYSIS

Prior to a discussion of the method used to solve the penetration problem in the air-to-sediment case and the modifications required for use at sea, it is suitable to quote directly from Terzaghi and Peck [1948].

> "Because of the unavoidable undertainties involved in the fundamental assumptions of theories and in the numerical values of the soil constants, simplicity is of much greater importance than accuracy. If a theory is simple, one can readily judge the practical consequence of various conceivable deviations from the assumptions and act accordingly. If a theory is complicated, it serves no practical use until the results are condensed into graphs or tables that permit rapid evaluation of the final equations on the basis of several different assumptions."

A. ASSUMPTIONS THAT PERTAIN TO THE SEDIMENT

Deep-sea sediments are not well defined in the literature dealing with soil mechanics. Therefore a list of important assumptions considered in developing the penetration prediction method are stated:

1. The sediment is completely saturated with sea water.
2. The water content of the sediment is 75 percent or more, as is typical of marine deposits in the deep ocean basins.

3. Organic material that would tend to bind the sediment particles together is either absent or is present in very small quantities.

4. The sediment will fail along its weakest plane.

5. The only shear resistance is cohesion.

6. The initial penetration takes place in such a short time that the effect of permeability is nil. In a study of time-dependent deformation of clays Barden [1969] noted that the effect of adsorbed water on individual particles was that pore pressure equals the applied pressure at the first application of load.

7. Any lithification or cementation that may have developed along individual particle-to-particle contacts is broken at the time of impact. This implies a portion of the sediment is remolded at impact. If the particles do not react with one another by other than mechanical means, the mixture will behave as a viscous fluid [Peck and others, 1953, Pazwash and Robertson, 1969].

8. Shear strength varies in an irregular manner with depth. The variation of velocity gradients is greater in the deep ocean basins than over shallow areas [Ewing and Nafe, 1963] which implies that deep ocean sediments have been deposited in layers. This is confirmed by visual observation of deep-sea core samples which often show horizontal layers of different colors and textures. When studying in-situ strengths, Inderbitzen [1970] found that horizontal variations were much less than vertical variations. He also

found that the percentage of variation in shear strength decreased with depth, which may indicate that biological and chemical processes are taking place in the upper layers and minimal consolidation occurs.

9. The bulk wet density of the sediment can be considered constant with depth in the surficial sediments. The shear strength of a saturated sediment depends to a large extent on the structural arrangement of the particles and Scott [1967] points out that soils can have different structures at the same density, but may not have the same structure at different densities, which implies that shear strength is not a unique function of density. X-ray diffraction and polarized light microscope techniques cannot reveal the details of particle configuration or orientation in fine-grained marine sediments. However, electron microphotographs of sediments from the Gulf of Mexico show them characterized by a loose, open arrangement of randomly oriented particles and that particle rearrangement resulting from gravitational consolidation is not apparent [Bowles, 1969].

10. The energy transmitted to the sediments in the form of elastic or gravity waves from the initial impact shock is negligible in comparison to the total energy dissipated during penetration. Impacts on soils and fluid media have been studied for a long time, but there is a very difficult instrumentation problem with detecting energy transmitted away from the impact site. According to Hunter [in Schmid, 1966] the Hertz impact theory, which refers to impacts in the elastic

range, states that the portion of total energy that is vibrational energy is very small as long as the impact velocity is less than the velocity of sound in the medium. Schmid [1966] measured the distant dynamic disturbances caused by a small penetrometer impacting into materials whose rheological properties were known or easily tested, such as, greases, wax, and homogeneous soils. High frequency vibration was detected in the hard materials and it was determined by use of surface accelerometers that the largest amount of energy propagated from the point of impact was 4.3 percent of the total energy available. His calculated propagation speed suggested that the motions measured at the surface were Stoneley waves. Ochi and Bledsoe [1962] when conducting model tests of ship hull forms slamming onto a water surface found that forces were very large for .01 seconds and pressure due to impact phenomena were over within .07 seconds, yet the model's velocity decrease during this time was less than 4 percent. Chuang [1970] in a similar investigation, did not detect any significant acoustic pressure variations at a distance away from the impact point and concluded that water could be considered incompressible for impact velocities from 0 to 50 feet per second.

B. METHOD OF SOLUTION FOR THE AIR-TO-MUD CASE

A rational, phenomenological approach was used to solve the penetration problem rather than an empirical method because of the poor state of knowledge that exists relative to actual behavior of deep-sea sediments. With engineering

judgment, this method may be extended to different objects and different cases more easily than an empirical approach to the problem.

1. Role of Hydrodynamics

The sediment was treated as a homogeneous, incompressible fluid to enable an estimate to be made of (1) the momentum transferred from the body to the sediment, and (2) the drag forces exerted on the object at high velocities. If the sediment was a true fluid it would have an infinite strain for an applied stress. Therefore, the forces required to initiate failure in the sediment and bring the body to rest were taken as the forces calculated using the ultimate bearing capacity formula developed by Prandtl and Terzaghi.

Treating deep-sea sediments as fluids has been an approach applied to the study of turbidity flows and slumping on the continental slopes. The term "spontaneous liquefaction" is often used when referring to saturated clays and implies fluid properties. Briefly, Morgenstern [1967] states that liquefaction occurs when the sediment is loaded to the collapse stress of the sediment fabric and the load is then transferred to the interstitial pore water. The increase in pore pressure then produces hydraulic gradients which further disrupt the sediment fabric causing the solids and pore water to flow macroscopically as a viscous fluid. Houston and Mitchell [1969] describe the fluid phenomena as occurring in sensitive clays which contract during shear because of their open fabric. If the clays are saturated, the contraction tendency

results in a large transfer of normal stress from the clay skeleton to the pore water causing pore pressure to increase. In saturated deep-sea sediments this transfer of normal stress may be almost instantaneous. Continuing the description of Houston and Mitchell [1969], as the remoulding caused by continuing strain becomes more pronounced, the effective normal stress may fall to a very low value. Very little strain is required to break bonds at particle contacts and there is some build-up of pore pressure even before a significant number of bonds are broken because of slight elastic compression of the fabric and incompressibility of the pore water. The resistance of sensitive clays due to dilational energy was determined to be small or absent by Houston and Mitchell [1969], and Walker [1969]. Because, first, at high void ratios little or no tendency toward dilation was observed during shear, even at high strains, and second, the effective stress had been so reduced at high strains the mobilized resistance of the clay fabric was small. Mandl and Givens [1964] when conducting high velocity penetration tests into a clay, judged that the compressibility phase of impact lasted until the surface boundary breaks and that the static yield strength of the clay was exceeded by many orders of magnitude under impact and the clays behaved in a dynamic manner similar to a fluid. Schmid [1966] when conducting low velocity free-fall impact experiments on a clay also observed that liquefaction occurred.

Another reason to treat deep-sea sediments as a fluid was that their bulk wet density has a narrow range of variation

with depth in the upper layers of sediment and the assumption of a median density over the range of expected penetration is a good approximation.

2. Ultimate Bearing Capacity Equation

The bearing capacity of a soil is a measure of its ability to support a load relative to its limiting equilibrium. According to Harr [1966], the first rational approach to developing a method to predict ultimate load carrying capacity of a soil was provided by Terzaghi who recognized that if the three dominant factors contributing to bearing capacity, the weight of the soil, the effects of surcharge, and the strength parameter of the soil, could be assessed, a good estimate of bearing capacity would be obtained. Terzaghi chose as a model of the failure mechanism of the soil the solution to the problem of penetration of circular punches into metal as developed by Prandtl and Reissner. In the original solution Prandtl was able to neglect the effect of the weight of the metal moved to the influence of surface loadings on the surrounding material. When the material was assumed to be isotropic and homogeneous with no angle of internal friction, Prandtl's solution yielded,

$$q_d = \gamma D_t + 5.14c \qquad (16)$$

On the basis of experiments and Prandtl's solution, Terzaghi and Peck [1948] derived the following semi-empirical equation for the bearing capacity of a circular footing.

$$q = 1.3c\ N_c + \gamma D_f\ N_q + .6\ \gamma N_\gamma \qquad (17)$$

where q = pressure at surface to cause failure (psi)

c = cohesion or shear strength of the soil (psi)

γ = unit weight of the soil

D_f = depth of footing below the surface of the soil (in)

N_c, N_q, N_γ = factors which depend on the angle of internal friction and depth of footing

The first term represents a contribution due to the shear strength of the soil, the second the effect of material removed by putting the footing below the surface (equivalent to buoyancy in water), and the third term, the effect of an angle of internal friction (assumed to be zero for deep-sea sediments). The equation is modified slightly for square or oblong footings and Meyerhof [1961] gives constants for wedge and cone shaped footings. More complete discussions of the bearing capacity equation and slight variations in the values of the constants can be found in texts on soil mechanics [Terzaghi and Peck, 1943; Harr, 1966; and Hough, 1969]. Terzaghi's equation was the closest to Prandtl's (which requires theoretical failure surfaces) and it has been empirically verified for many years. It was therefore selected as a reliable relationship for estimating the static strength of deep-sea sediments. The values of the constants and the shapes used in equation (17) are given in Table I.

In the bearing capacity equation, the shear resistance mobilized on the failure surface of any surcharge material is neglected, hence the equation is conservative and relates only to events occurring below the footing or

penetrating object. During penetration, static resistance will occur in the undisturbed portion of the sediment below the deepest penetrating part, the other surfaces of the penetrating object are subjected to remolded sediment or sediment already set in motion by the penetrating object. Therefore the bearing capacity equation constants used in penetration prediction were considered to be for shallow footings for all depths of penetration.

3. The Character of Failure

Before a final method of solution was selected, motion pictures of penetrations into soft sediments and still photographs of soil failures were studied. In the motion pictures, the sediment was observed to move laterally outward from the object and have somewhat of a separation point from the object. While dropping plates vertically into a simulated sediment, Erchul [1968] found that polymer coatings to reduce drag on the plates had little effect at high entrance velocities and postulated that the sediment may not have been in contact with the plates. He also observed that at low velocities the lubricants did reduce adhesion to the plate and considerably greater penetration occurred with lubricated plates compared to unlubricated ones.

To find a qualitative indication of the effect of fluid in interstitial spaces, Rowe and others [1962] dropped probes into finely ground (less than 40 microns) silica dust. At atmospheric pressure the dust displaces laterally and craters were formed. In a vacuum with no air in the interstitial spaces, resistance to penetration was 100 percent

greater and the dust did not move laterally and no mounds or craters were formed.

The motion pictures of penetrating objects in the test pit revealed little splatter and little surface disturbance at a distance from the penetration point. Clark and Robertson [1965] observed motion pictures of a buoyant body exiting from water and came to the conclusion that energy lost due to surface effects was small. Moran [1965] also arrived at the same conclusion.

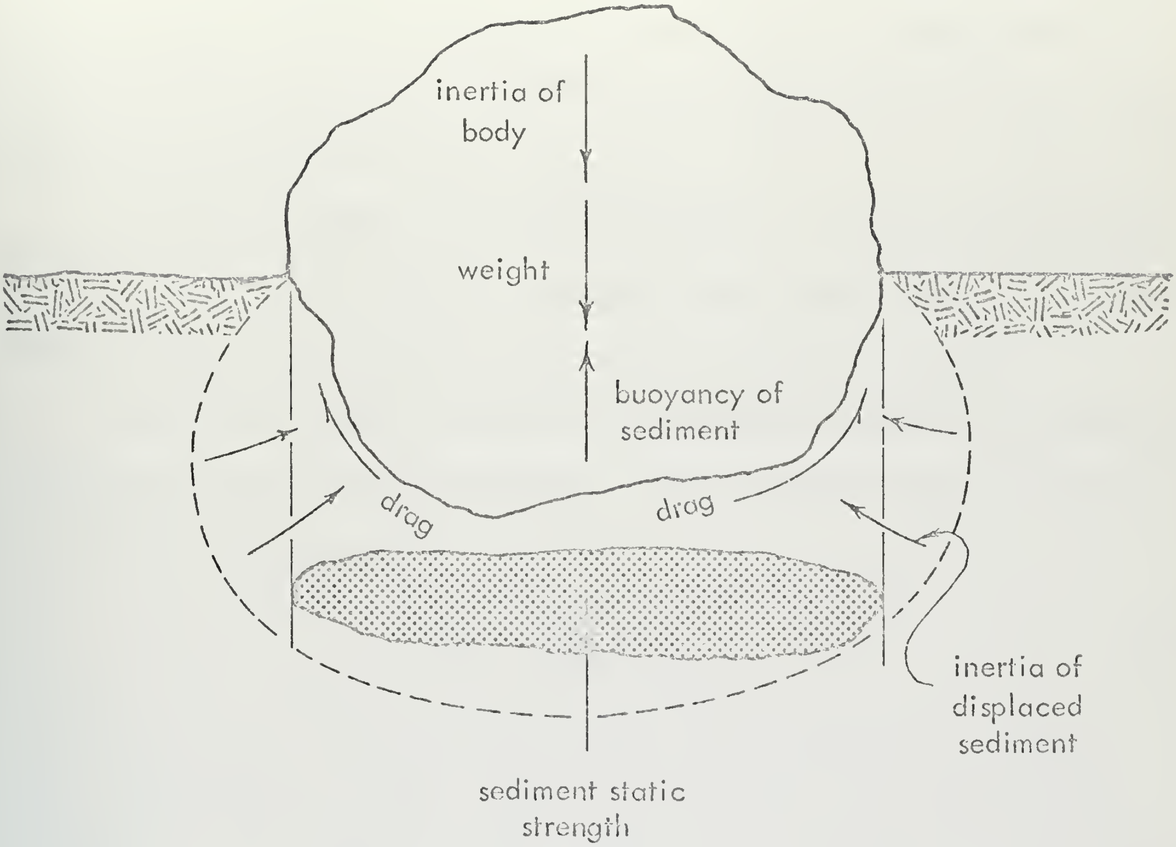
4. Equation of Motion

Since penetration is a dynamic phenomena involving the unsteady motion of a body, the first attempt at evaluating the penetration depth involved writing an equation of motion for the object as it penetrated the sediment. The final solution required a work energy approach that allowed the change in velocity and penetration depth to be determined incrementally with a computerized numerical scheme without the requirement to integrate the equation of motion and establish the instantaneous relationship between force, mass and acceleration.

The forces acting on an object penetrating a sediment characterized as a fluid with a static strength are shown in Figure 2. The equation of motion can be written as follows:

$$Ma = \sum \text{Applied Forces} \qquad (18)$$

Where the applied forces are: weight of the object, the sediment static strength, the buoyancy provided by the sediment, the force to overcome the inertia of the sediment, and the drag forces.



$$\underset{\text{body's inertia}}{-M\ddot{x}} = \underset{\text{weight}}{Mg} - \underset{\text{static strength}}{\rho_0} - \underset{\text{buoyancy}}{\gamma_s A x} - \underset{\text{sediment's inertia}}{m'\ddot{x}} - \underset{\text{drag}}{\frac{1}{2} C_d A \rho_s \dot{x}^2}$$

Figure 2. FORCES ACTING ON A PENETRATING OBJECT

The change of the body's motion as it penetrates the sediment is the equivalent of the resistance encountered by the body, or the energy involved in the change is equal to that expended in propelling the body. Momentum is transferred to a surrounding fluid by; (1) a certain volume of fluid being accelerated uniformly, (2) the fluid being put into turbulent motion, (3) compression waves, (4) gravity waves or spray [Hoerner, 1958]. All of the momentum is

eventually consumed by viscous friction. The last two modes of momentum transfer have been assumed to be negligible for the velocity ranges and object sizes under consideration and were discussed previously.

The treatment of the drag force, or the momentum put into the fluid by turbulent motion and viscous drag, outlined below, follows that given by Mandl and Givens [1964].

The drag forces cannot be evaluated easily for unsteady motion through a fluid boundary. The coefficient of drag can be approximated by;

$$C_d = (\frac{\beta}{Re} + C_{D_\infty}). \qquad (19)$$

The first term represents the contribution due to viscous drag; the second is that due to form drag; β is a constant depending on the shape of the body and is usually represented by the first term in an infinite series (Oseen's approximation). For a circular disk placed broadside to a stream $\beta = \frac{64}{\pi}$, while for a sphere $\beta = 24$ (Lamb). The term C_{D_∞} corresponds to the asymptotic case as Reynolds number approaches infinity in Navier-Stokes flows, it depends on geometry and not the fluid dynamic properties. Inspection of experimentally obtained drag coefficients versus Reynolds number relationships for bluff bodies show that C_d is a slowly varying function at large Reynolds numbers. For bluff bodies with sharp edges nearly all the drag is form drag. The experimentally determined values of C_{d_∞} in the case of bodies with sharp edges is approximently 1.0. For bluff bodies without sharp edges, such as spheres, the form drag also depends on the position

of flow separation which in turn depends on the critical range of Reynolds numbers. The equation of motion then becomes:

$$(m'+M)\ddot{x} = Mg - p_o - \gamma_s Ax - \frac{1}{2} A \frac{\beta \mu}{D\rho_s \dot{x}} - \frac{1}{2} \rho_s AC_{d_\infty} \dot{x}^2 \qquad (20)$$

If the viscosity of clay is taken to be on the order of 3×10^{-3}, lbs - sec/in^2 [Whitman in Mandl and Givens, 1964], the Reynolds number for the objects that were under study with a three foot maximum dimension and with a velocity of ten feet-per-second, is on the order of 2×10^2. Admittedly a constant value of viscosity for a rheologically complicated substance such as a deep-sea clay is a gross over simplification, but the order of magnitude of the terms indicates that the viscous drag contribution to the equation of motion may be ignored [Mandl and Givens, 1964]. Also, towards the terminal phase of motion where the effect of viscosity is liable to increase rapidly with decrease in the rate of strain, the influence of viscosity will be negligible since the velocities are small and the other terms in the equation are larger by several orders of magnitude. Since form drag represents pressure forces on the body which are significant at the higher velocities, it could not be neglected.

5. Added Mass Effects

Another reason to treat the sediment as a fluid was to have a method available to estimate the volume and velocity of sediment displaced as the object penetrated. Womack [1967] verified that the amount of saturated clay moved during penetration was equal to the size of hole created.

The energy required to move the sediment is conserved since once the sediment is put in motion by the object it will continue to move away from the object creating a larger crater as the object is slowed by other forces. It is very important though, because the drag term of the equation of motion is dependent on velocity squared and the inertial effect of the sediment motion will alter the velocity-time history of penetration which has significant effects depending upon the shape and impact velocity of the object.

Added mass is caused by hydrodynamic pressure forces which are proportional to the instantaneous values of acceleration and according to Wendel [1950] appear to have the same value in a viscous or inviscid fluid as long as small bodies are not involved. The added masses were determined according to equations and methods given by Saunders [1957], which are tabulated in Table II.

The assumptions pertaining to the fluid approximation of deep-sea sediments can be summarized as follows and are the same as given by Moran [1965] in a study of water entry and exit.

1. Irrotational flow - viscous effects on the pressure felt by the body are generally small and the variations in inviscid forces are more important than viscous drag.

2. Incompressible flow - impact velocities are well below the speed of sound.

3. Surface effects are negligible.

The problem with determining depth of penetration from equation (20) is that it cannot be integrated during the unsteady motion of an object transiting a fluid boundary from one fluid to another. This is true for the following reasons: (1) m', the added mass and mass of the displaced sediment, is a function of depth of penetration for an object whose submerged portion changes shape as it submerges; (2) the dominant term, that of static soil strength, varies with the depth in a highly irregular manner; (3) the location of the air-to-sediment boundary condition is unknown a priori; and finally, (4) the flow is unsteady.

6. Transformation of the Equation to Work-Energy

The equation of motion may easily be resolved into an equation of energy and work which is time independent and a function of increments of distance. The development is given below.

$$\sum F_x = M \frac{d^2x}{dt^2} \tag{21}$$

Multiplication by dx gives

$$\sum F_x \, dx = M \, dx \, \frac{d}{dt} \left(\frac{dx}{dt}\right) = M \, \frac{dx}{dt} \, d \left(\frac{dx}{dt}\right) \tag{22}$$

The first integral with respect to displacement is:

$$\int F_x \, dx = 1/2 \; M \left(\frac{dx}{dt}\right)^2 + C \tag{23}$$

The left hand term represents the work done on M during the interval dx and can be evaluated if F_x is a known function of x. The right hand term represents the corresponding change in kinetic energy of the object.

Kinetic energy is a scalar quantity that depends only on the mass and magnitude of the velocity. Since the velocity is squared it is always positive. The total mechanical energy of the body is equal to:

$$E = KE + PE \tag{24}$$

For an object penetrating the sediment and coming to rest, the energy of the object can be accounted for by:

$$E_1 + E_{IN} - E_{OUT} = E_2 \tag{25}$$

This simple balance states that the total energy E_1 of the object at the beginning of an interval plus any energy put into the object minus any energy taken out must equal the final energy, E_2, of the object at the end of the interval. When the object has lost its energy in overcoming buoyancy, static soil strength, inertia of the sediment, and drag, it will stop its motion.

A particular reference level for the energies is not needed since energy is relative. The potential energy depends on an arbitrary selection of datum for zero potential. Also the kinetic energy is arbitrarily expressed relative to the condition at zero velocity. Hence any physical measurement over an interval describes a change in energy. It follows that reference to an arbitrary datum used for the expression of energy will cancel.

The work-energy method approach to solving a problem is powerful but dangerous because an answer is always obtained with no indication that the answer is correct. The method balances work to equal energy available and if a portion of

of the energy available is not considered, or incorrectly computed, work is still done and an answer results. In the unsteady case of penetration, using an iterative solution almost requires a computer because errors in computation will not be indicated but will appear as energy gained or lost. The answer will not appear wrong unless a gross error was made.

In analysis of the penetration problem only mechanical energy was considered, with the sediment and object being a conservative system in the gravitational field. Thermal, chemical, electrical and atomic energies were neglected.

7. Method of Solution Used with a Computer

The numerical iteration scheme used to solve the penetration problem was the same for each object shape. Briefly, it divided the object into sections or slices in the same plane as the sediment surface. Then the work necessary to submerge each section and the work done by the sum of the submerged sections, the forces due to the inertia of added mass and displaced mass of the sediment, the static strength of the sediment, and drag in moving an incremental distance equal to a section thickness were calculated and subtracted from the kinetic energy and change in potential energy of the object. Penetration depth was determined when the total kinetic energy of the object equaled zero.

A description in mathematical terms follows and a block outline of the computer solution is shown in Figure 5.

Constants and necessary approximations for each object are listed in Table I. The computer programs are included as Appendixes C through H.

Refer to Figure 3 for an explanation of the definitions that follow.

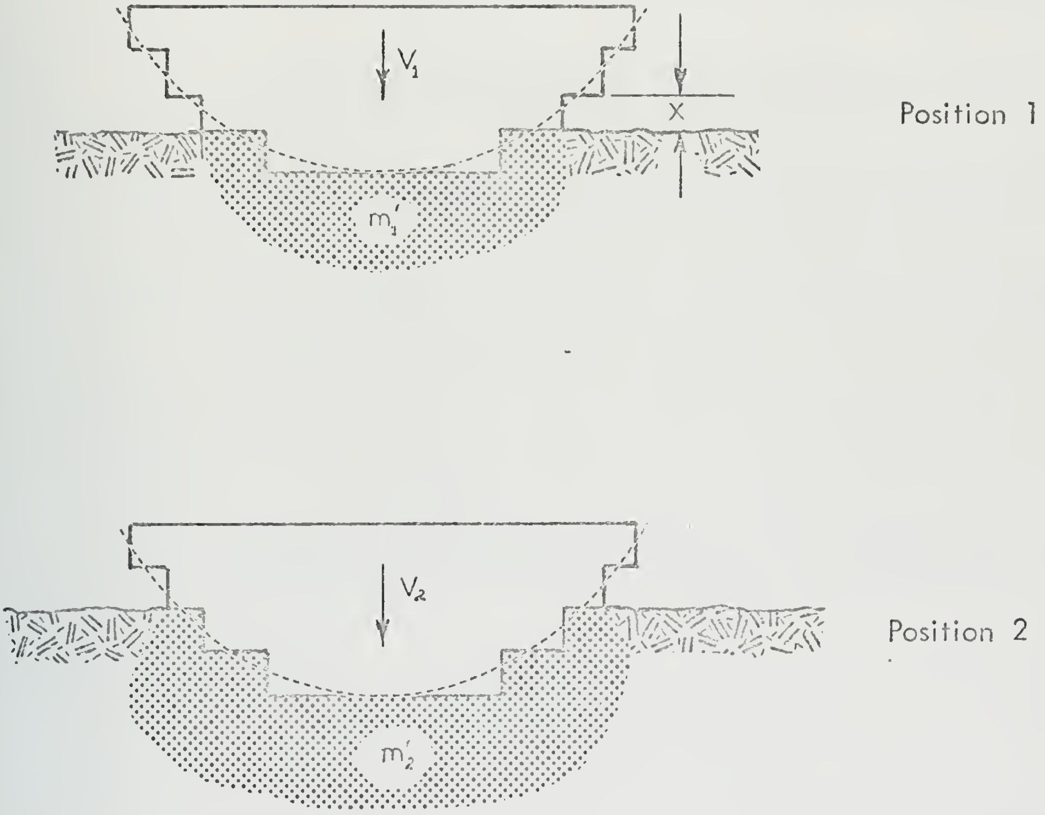


Figure 3. DEFINITIONS

v_1 = average velocity of the object as it transits distance x from position 0 to position 1. (Assumes a linear velocity gradient)

v_2 = average velocity of the object as it transits distance x from position 1 to position 2

M = mass of the object

m'_1 = added mass at section 1, plus the mass of displaced fluid at section 1

m'_2 = added mass at section 2, plus the mass of displaced fluid at section 2

$\Delta m = m'_1 - m'_2$

U = work done

U_b = work done against buoyancy forces as object transits from position 1 to position 2

U_s = work done against sediment static strength as the objects transits from position 1 to position 2

U_d = work done against drag forces as the object transits from position 1 to position 2

ΔU = the change in energy of the body as it transits from position 1 to position 2, not including change in potential energy

E_1 = total energy of the object at position 1

E_2 = total energy of the object at position 2

ΔPE = change in potential energy of the object over distance x

From equation (22)

$$U = \int_{v_1}^{v_2} m' \, v \, d \, v \tag{26}$$

$$U = 1/2 \; m' \; v_2^2 - 1/2 \; m' \; v_1^2 \tag{27}$$

it follows that

$$\Delta U = 1/2 \; m'_1 \; v_2^2 - 1/2 \; m'_1 \; v_1^2 + 1/2 \; m' v_2^2 + U_b + U_s + U_d \tag{28}$$

NOTE: 1. $\Delta m'$ was accelerated from a static condition, zero velocity to the velocity at the end of the section over which it was computed.

2. $\Delta m'$ was assumed to be zero after the object had penetrated to its maximum dimension since separation of the sediment from the object was apparent at this point.

The incremental distance, x, is fixed, and the various masses are known as is the work necessary to move the object from position one to position two. Velocity at position two is unknown. Therefore from the work energy relationship

$$E_2 = E_1 + PE - \Delta U = 1/2\ Mv_2^2 \qquad (29)$$

Combining equation (28) with (23) and solving for v_2 gives

$$v_2 = \sqrt{\frac{2(\Delta PE + E_1 + 1/2\ m_1'\ v_1^2 - U_b - U_s - U_d)}{(M + \Delta m' + m_1')}} \qquad (30)$$

In the iteration scheme, when v_2 equals zero, the sum of the increments, x, is the penetration depth.

The work done against buoyancy forces is a straightforward calculation that is discussed in elementary fluid mechanics texts. In the computer iteration scheme where the sections of an object are taken to be slices with vertical sides it becomes;

$U_b = 1/2\ \gamma\ A\ x^2$ (for the section being submerged)

plus $\sum \gamma\ A\ x^2$ (for all sections below the one being submerged)

The work done against drag forces was taken to be:

$$U_d = 1/2\ \rho C_{d_\infty}\ A\ v^2\ x \qquad (31)$$

where γ = bulk wet density of the sediment

C_{d_∞} = drag coefficient for the approximate object shape that is below the sediment surface

A = the maximum cross sectional area of the object below the sediment surface and normal to the velocity vector

v = average velocity over the distance moved, assuming a linear variation in velocity.

The work done against the sediment static strength was calculated from the ultimate bearing capacity equation.

$$U_s = C_f N_c A c x \tag{32}$$

where C_f = a constant depending on footing shape

N_c = a constant depending on the type of sediment and footing profile

c = shear strength of the sediment

When the penetrating object had a flat plane forcing into the sediment such as a cylinder impacting on end, the cross sectional area, A, of the flat area and the shear strength, c, of the sediment at the penetration level of the flat area were used in the equation above. In the case of objects with rounded or sloping sides, a judgment had to be made of a cross sectional area and representative shear strength. The area selected was the maximum cross sectional area normal to the velocity vector at the surface of the sediment, or the maximum cross sectional area of the object if the area had penetrated beneath the sediment surface. This method of approximating a sloping or curved surface by a projected horizontal area appears valid for blunt objects [Meyerhof, 1967]. Since the shear strength characteristics of deep-sea sediments in the upper layers appear to change radically with depth in the sediment column, a shear strength for equation (32) was determined by selecting an average

depth according to the zones of plastic failure implied by equations (16) and (17). This was selected as one-half of the penetration depth until the maximum cross sectional area had been reached, then it became the depth of penetration minus one half the penetration depth when the maximum cross sectional area was coincident with the surface of the sediment as illustrated in figure (4).

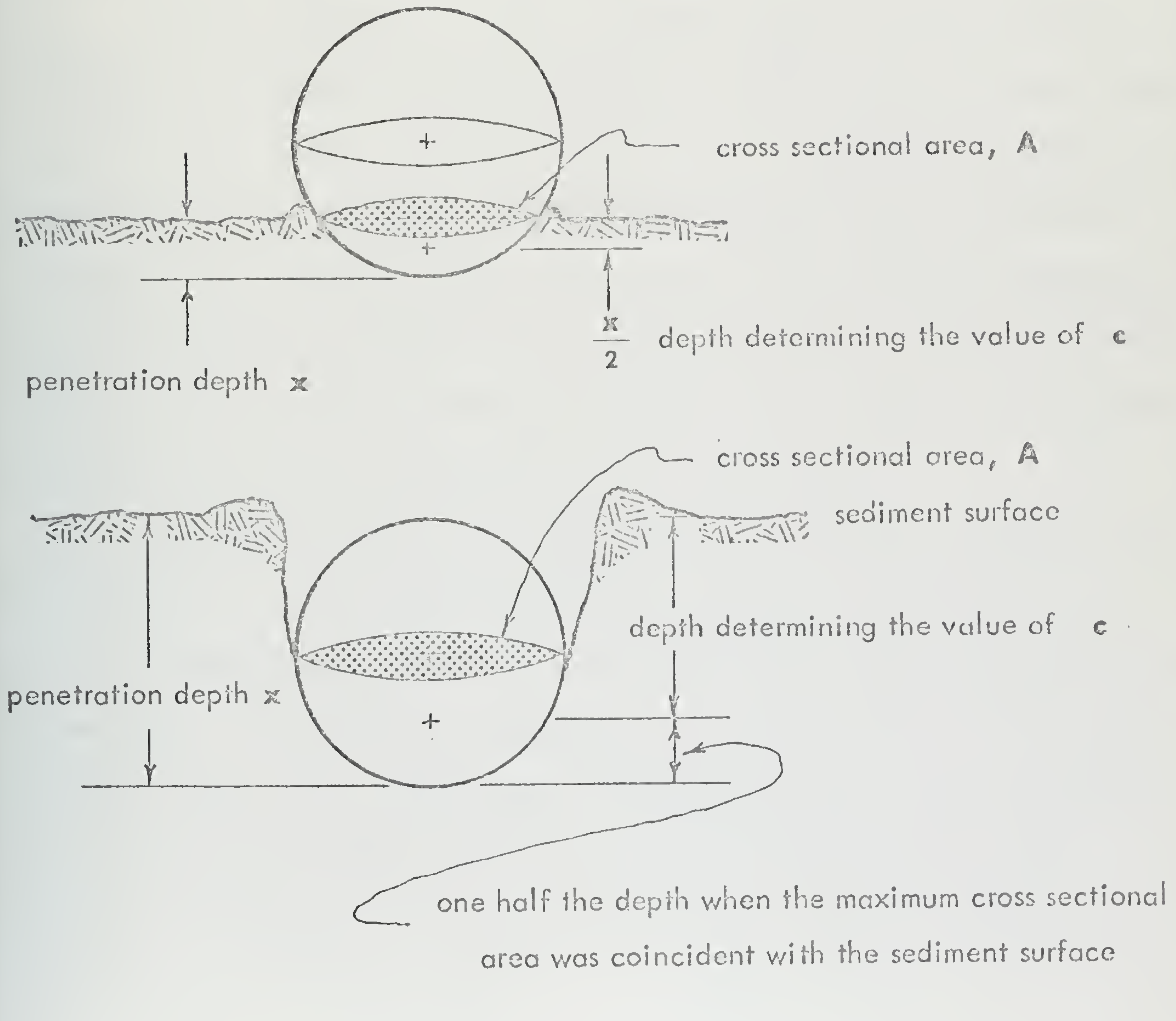

cross sectional area, A
$\frac{x}{2}$ depth determining the value of c
penetration depth x
cross sectional area, A
sediment surface
depth determining the value of c
penetration depth x
one half the depth when the maximum cross sectional area was coincident with the sediment surface

Figure 4. DETERMINING THE DEPTH OF "c" FOR NON-FLAT OBJECTS

The method described was adequate for curved and conical objects and approximates a representative strength in the theoretical zones of plastic failure in the sediment. An alternative and more refined method of selecting A and c, would have been to use the differences in the cross sectional area from section to section and apply the value of c at the depth of each section. This increased the complexity of the iteration procedure, hence was attempted only when there were discontinuities in the penetrating object's shape such as might occur with a truncated cone.

The distance of each iteration was chosen only to conserve computer time and approximate the expected accuracy of the field tests. Larger and smaller iteration intervals were tested for effects on the final depth and as long as the interval was less than one-half of the distance between shear strength measurements, convergence was always apparent. With a linear shear strength profile, the interval is limited only by the desired accuracy of the solution.

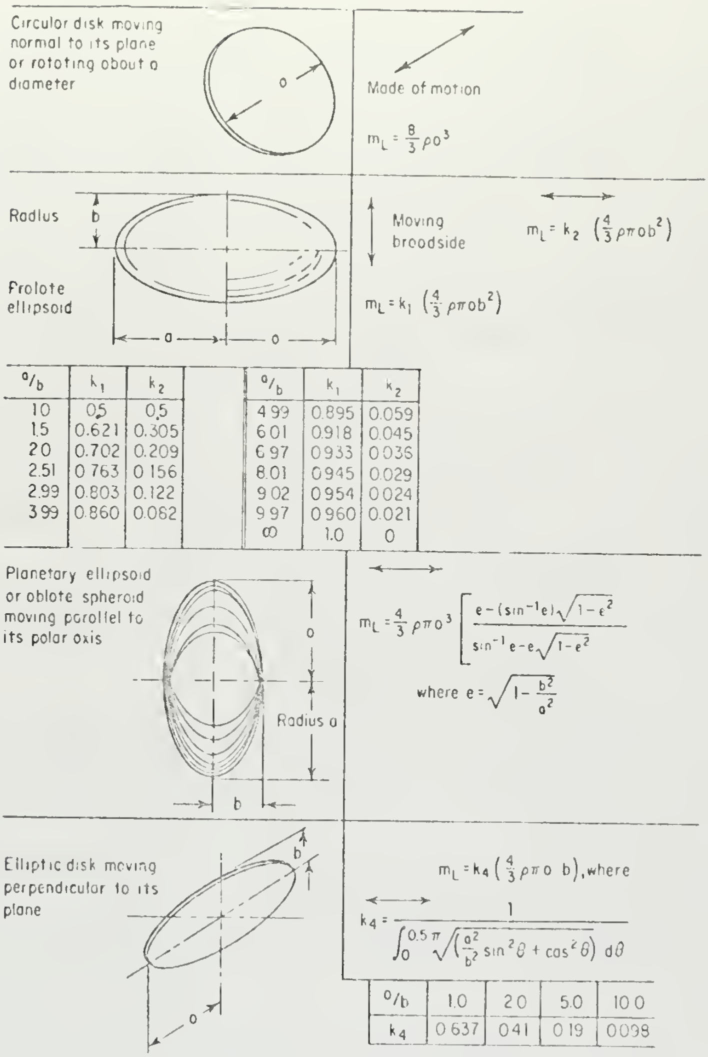
The equations for added mass are given in Table II. A flow chart of the basic program is given in Figure 5.

Appendix A presents a set of curves which qualitatively illustrate the relative influence of each force in the penetration equation. They were obtained by using the sediment shear strength profile typical of the world's deep-ocean basins as determined by Hoag [1970] and shown in Figure 13.

OBJECT	SECTION FORM	COEFFICIENT OF DRAG[1]	FOOTING SHAPE FACTOR[2]	BEARING CAPACITY FACTOR[2]	APPROXIMATION SHAPE FOR COMPUTING ADDED MASS
Sphere	Cylinder	0.3	1.3	5.7	One half of an oblate spheroid moving parallel to its polar axis
Horizontal Cylinder	Rectangular Parallelepiped	0.68	1.3	5.7	One half of a prolate ellipsoid moving broadside with projected area equal to the area of the section form with the same ratio of maximum and minimum dimensions
Cylinder-On-End	Cylinder	0.3	1.3	5.7	One half of a circular disk moving normal to its plane
Cube	Square	1.1	1.3	5.7	One half of a circular disk with an area equal to the area of a square moving normal to its plane
Rectangular Parallelepiped	Rectangular Parallelepiped	1.0	1.3	5.7	One half of an elliptical plate with the same area and ratio of maximum and minimum dimensions of the section form moving normal to its plane (k = .51)
Cone	Cylinder	0.3	1.0[3]	4.7[3]	One half of a prolate ellipsoid moving on its long axis (k = .095)

Table I. CONSTANTS AND SHAPES USED FOR COMPUTATIONS

(see next page for footnotes)



Circular disk moving normal to its plane or rotating about a diameter

Mode of motion

$m_L = \frac{8}{3}\rho a^3$

Radius b

Prolate ellipsoid

Moving broadside

$m_L = k_2\left(\frac{4}{3}\rho\pi a b^2\right)$

$m_L = k_1\left(\frac{4}{3}\rho\pi a b^2\right)$

a/b	k_1	k_2
1.0	0.5	0.5
1.5	0.621	0.305
2.0	0.702	0.209
2.51	0.763	0.156
2.99	0.803	0.122
3.99	0.860	0.082
4.99	0.895	0.059
6.01	0.918	0.045
6.97	0.933	0.036
8.01	0.945	0.029
9.02	0.954	0.024
9.97	0.960	0.021
∞	1.0	0

Planetary ellipsoid or oblate spheroid moving parallel to its polar axis

Radius a

$$m_L = \frac{4}{3}\rho\pi a^3\left[\frac{e-(\sin^{-1}e)\sqrt{1-e^2}}{\sin^{-1}e-e\sqrt{1-e^2}}\right]$$

where $e = \sqrt{1-\frac{b^2}{a^2}}$

Elliptic disk moving perpendicular to its plane

$m_L = k_4\left(\frac{4}{3}\rho\pi a\ b\right)$, where

$$k_4 = \frac{1}{\int_0^{0.5\pi}\sqrt{\left(\frac{a^2}{b^2}\sin^2\theta + \cos^2\theta\right)}\,d\theta}$$

a/b	1.0	2.0	5.0	10.0
k_4	0.637	0.41	0.19	0.098

Table II. FORMULAS FOR CALCULATING ADDED MASS[4]

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[1] Hoerner, S. F., Fluid Dynamic Drag, Practical Information on Aerodynamic Drag and Hydrodynamic Resistance, Chap. II, Published by the author, Midland Park, New Jersey, 1958.

[2] Terzaghi, Karl and Peck, Ralph B., Soil Mechanics in Engineering Practice, p. 172, John Wiley and Sons, 1948.

[3] Meyerhof, G. G., "The Ultimate Bearing Capacity of Wedge Shaped Foundations", Proceedings, 5th International Conference Soil Mechanics and Foundation Engineering, v. 2, p. 106, Paris, 1961.

[4] Saunders, Harold E., Hydrodynamics in Ship Design, v. II, p. 421, The Society of Naval Architects and Marine Engineers, 1957.

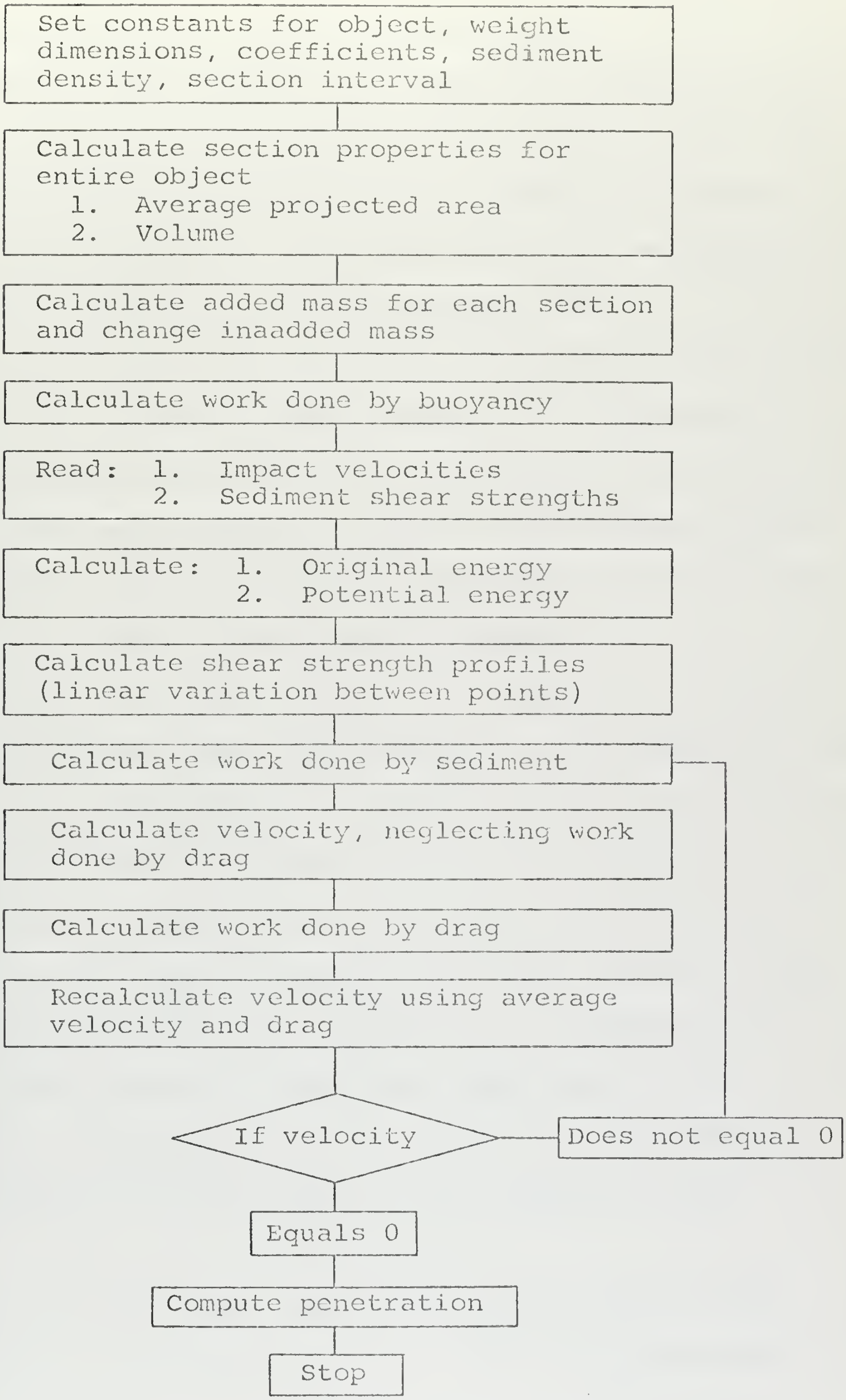

Set constants for object, weight dimensions, coefficients, sediment density, section interval
Calculate section properties for entire object
1. Average projected area
2. Volume
Calculate added mass for each section and change inaadded mass
Calculate work done by buoyancy
Read: 1. Impact velocities
2. Sediment shear strengths
Calculate: 1. Original energy
2. Potential energy
Calculate shear strength profiles (linear variation between points)
Calculate work done by sediment
Calculate velocity, neglecting work done by drag
Calculate work done by drag
Recalculate velocity using average velocity and drag
If velocity
Does not equal 0
Equals 0
Compute penetration
Stop

Figure 5. OUTLINE OF COMPUTER PROGRAM

C. MODIFICATION OF THE METHOD FOR USE AT SEA

The method was ultimately developed for general use at sea with as few restrictions as possible placed on size and shape of the object and on the type of sediment. However the only data available to test and verify the method was for an air-to-simulated deep-sea sediment case.

There are three relatively simple alterations that should be made to the computer program before it can be used in a water-to-sediment case. The three alterations should act to increase penetration depths at higher velocities and their overall effect is to increase the importance of an accurate determination of the shear strength profile.

First, the added mass effects will change by the ratio of the density of sea water to the density of the sediment. This can easily be accomplished by dropping the unit value of sea water from the bulk wet density term in the programs. Additionally, the added mass of the object free-falling through the water must be added to the total kinetic energy of the object at impact and a method for calculating the effect of this entrained water mass taken into account.

Second, the buoyancy term will also change by the ratio of the density of the sea water to the density of the sediment.

Third, the drag term will change by the ratio of sea water density to sediment density. Also a drag term must be included for the part of the body that projects above the sea-sediment interface. The easiest way to accomplish this

would be to include a drag term for the whole object and add a drag term for the portion of the object submerged in the sediment.

The three modifications will serve to reduce the influence of added mass, buoyancy and drag and cause the sediment static strength term to become even more dominant than in the air-to-sediment case. Keller [1964], used the standard bearing capacity equation, only, to predict the initial settlement depths of a rectangle, square, and cylinder into soft bay sediments. The results were poor and he concluded that problems with determining an accurate strength of the sediment were the reason his calculations always underestimated the settlement depth.

To correctly use the method at sea, several cores should be taken and their physical and mechanical properties averaged. Averaging should reduce errors caused by sampling and testing disturbances. The effect of sensitivity, as it applies to the shear strength used in computing penetration depth, is uncertain. Possibly the remolded shear strength is a better value if it is assumed that impact shock effectively remolds the sediment to an unknown extent. In sensitive sediment, a range of predicted penetration depths should be calculated according to the degree of sensitivity.

The orientation that the object has as it first starts to penetrate has a significant effect on total penetration. After free-fall in several thousand feet of water, the object may still be tumbling or oscillating if it is unstable.

Schmid [1966] found that a significant portion of a falling body's energy may be in its angular momentum which is not included in this method.

For these reasons when predicting penetration depths, a computer routine should be used to solve for a range of impact velocities, shear strength profiles, and object orientations. The calculations can be done by manually using larger intervals, as was done to check the first computer solutions, but since energies are being equated and the method is iterative, extreme caution must be used since an answer, correct or not, always results.

IV. RESULTS OF EXPERIMENTS

A. THE PROBLEM OF MODELING IN SOILS

Some problems with testing and modeling the dynamic behavior of soils are discussed before reviewing the data available to test the penetration prediction method and the results of the tests.

The field of soil mechanics has traditionally been concerned with large scale construction operations. Many of the methods used to calculate the stability of slopes and foundation designs are based on ultimate collapse criteria and much of what has been learned about soil behavior was derived from studies of catastrophic large scale failures. Big construction projects are seldom undertaken without expensive, full-scale, field tests of critical portions of the foundations, and modern buildings are carefully instrumented to monitor their settlement and reaction to seismic disturbances. A good indication of the state-of-the-art of soil mechanics is implied in the large safety factors recommended in texts and building codes. The lack of understanding is, in large measure, due to the inability to parameterize and model a substance as complex as a soil.

When the problem is narrowed to the field of saturated deep-sea sediments, the problems of modeling are somewhat reduced. A modeling approach to investigate the dynamic response of soils to impulsive loads was conducted by Westine [1966] who found that a satisfactory case could be made for

a model with saturated clays, but granular materials with angles of internal friction were impossible to simulate, since dilation and pore water pressures were hard to model. Frolich [1967] attempted to model the dynamic behavior of submarine sediments, but unfortunately he passed away before publishing his final results.

There are several areas where modeling dynamic penetration phenomena in deep-sea sediments may prove to be impossible.

Under dynamic loads a saturated deep-sea sediment may behave as a bingham body. The inertial resistance of the sediment to deformation coupled with the threshhold stress, or static resistance of the sediment, may be very hard to separate if the mass and therefore, inertia, of the penetrating body is small or on the same order of magnitude as the static resistance and inertial resistance of the soil. An analogous problem, but simpler by one factor, is unsteady fluid flow at low Reynolds numbers where inertial and viscous forces are the same order of magnitude. In the dynamic testing of soils this problem can be circumvented by full-scale tests using objects with large masses.

A similar problem involves surface effects and the adhesion of deep-sea sediments to an object. The effects of adhesion have been shown to be influenced by polymer coatings, surface roughness, surface chemical composition, etcetera, by Erchul [1969] and other investigators studying pile driving on land. Surface effects may control penetration

significantly if the object has a large surface area in relation to its total mass. A means of minimizing adhesion effects would be full scale tests with large masses.

If a study's purpose is to learn more about adhesion, or mass effects, then modeling may be the best approach. However extrapolation of modeled test results to objects larger by an order of magnitude may be invalid.

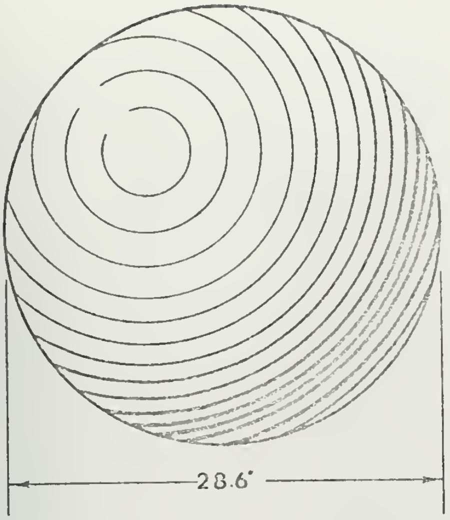
Finally, when attempting to model a sediment composed of clay particles which are very small, to reduce them further by an attempt at modeling the interparticle attractive forces and pore water viscous effects, may be impossible. Also, the instruments available to measure the modeled sediment strength may not have the required accuracy or precision for a reduced scale.

B. DATA AVAILABLE

The Naval Ordnance Test Station, Pasadena, California, constructed a large pit from sheet piling, 37.5 feet in diameter, and filled it to a depth of 16 feet with a very weak sediment from Seal Beach Lagoon, California. The pit was used to conduct tests on the holding strength of anchors, breakout forces of objects imbedded in the mud, and experiments with dynamic penetration. The penetration experiments were carried out under the direction of Dr. R. J. Smith in September, 1965. The penetration experiments are described below.

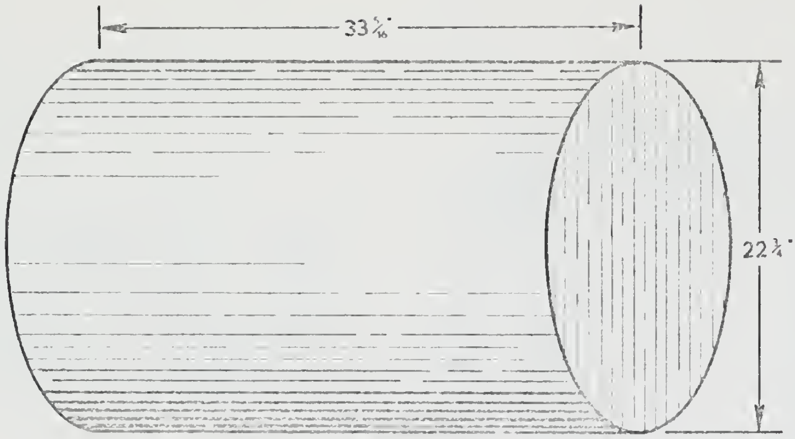
1. Description of Objects and Tests

Figures 6 through 11 show the six different objects that were dropped into the test pit. All six were fabricated



The sphere was made of a heavy steel plate and weighed 561 pounds in air. A padeye provided an attachment point for lifting.

Figure 6. SPHERE



The horizontal cylinder was made from a 55 gallon oil drum. It weighed 540 pounds in air. It was lifted by a two pennant bridle with one pennant welded at each lip.

Figure 7. HORIZONTAL CYLINDER

The cylinder-on-end was also made from a 55 gallon oil drum. For the first tests it weighed 540 pounds in air. Later a flat, round plate was welded over the lip of the drum at the end that penetrated, making it smooth to reduce the amount of air that might have been trapped there. The plate increased the weight to 561 pounds in air. The drum was lifted by a three pennant bridle attached to its upper end.

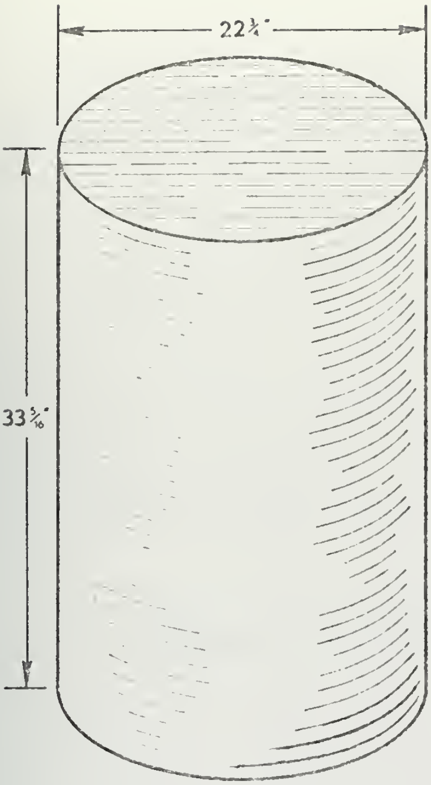


Figure 8. CYLINDER-ON-END

The cube was fabricated from steel plate and weighed 702 pounds in air. It was lifted by a four pennant bridle to each corner of one face.

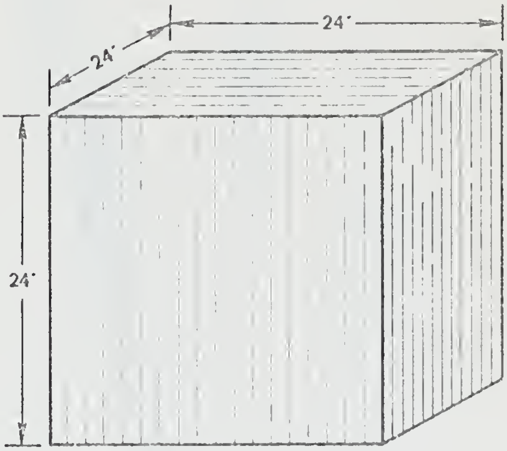
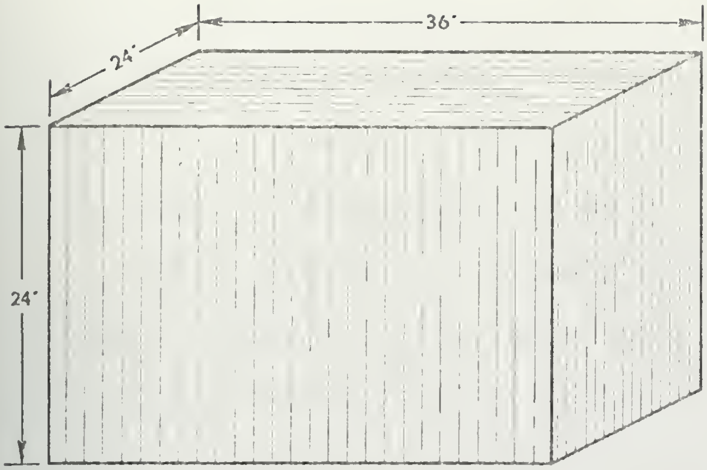


Figure 9. CUBE



The rectangular parallelepiped weighed 1,014 pounds in air. It was constructed of steel plate and lifted with a four pennant bridle to four corners of a large side.

Figure 10. RECTANGULAR PARALLELEPIPED

The cone was fabricated of steel plate and weighed 1,127 pounds in air. It was lifted by a three part pennant to the flat side and dropped point down.

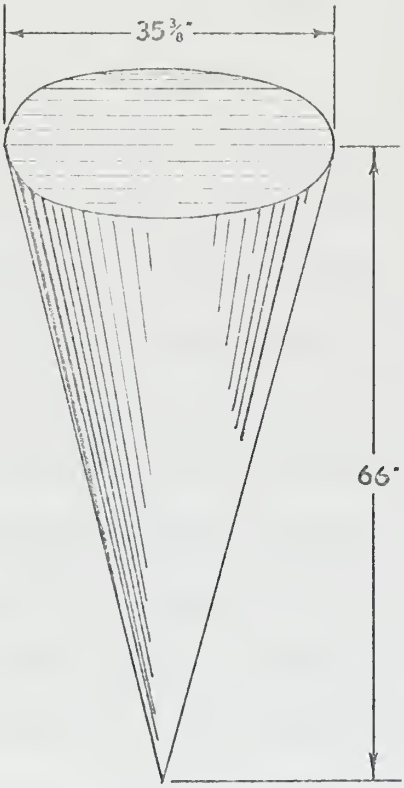


Figure 11. CONE

with a steel shell for structural rigidity and the cavity of the shell was completely filled with fresh water for weight. The weight could be changed if desired, however for penetration tests they were pressed full at all times. Dimensions of the objects are shown in inches.

The objects were suspended by a crane over preselected stations in the mud pit. They were released by a quick release hook that was tripped manually by pulling a line from the side of the pit. The objects were released at different heights above the mud-air interface to allow them to reach velocities of 5, 10, 15, and 20 feet per second as the object's lowest portion contacted the sediment-air interface. The zero velocity test was considered to be a zero release height, and the object was released with its lowest portion just in contact with the sediment-air interface.

Slow motion pictures, 32 frames per second, of almost all the penetrations were available. They were carefully studied in a frame-by-frame projector to double check the rough data sheets for height of drop and penetration depth. The movies also gave an indication of the stability of the object as it penetrated. Remarks about each penetration are given in Table X. Times for penetration and times for rebound were estimated by counting the frames of the movie film for each event. The movies confirmed the observations of Chuang [1970] that air trapped below a body impacting on a fluid does not alter the penetration depth. Any air that was trapped below the body usually vented by bubbling up

alongside the object after it had come to rest. Only in one or two cases was it observed to form a jet with a significant amount of entrained mud.

The penetration depth was determined by visual observation of marks painted on the objects which were scales divided into one quarter inch increments. The depth reference was the undisturbed surface of the pit. Depth observations were made at each corner of the rectangular objects and at a diameter of the axisymmetrical objects. The penetration depth was considered to be the numerical mean of the several measurements. Any exceptions to this method and angles of tilt at the object's final rest position are noted in the remarks column of Table X. The exceptions occurred when the cylinders-on-end tipped completely over after coming to rest. The penetration before tipping was used if it could be read from the movies with an accuracy of one half inch.

2. Description of the Sediment

There was a real problem finding a suitable material to simulate a true deep-sea sediment, compounded by the 700 cubic yards of material required to fill the test pit. The material selected was lagoonal mud, described as "unconsolidated grey sediment with medium sand sized mica flakes", from the tidal flats of Seal Beach Lagoon. Tables III through V contain detailed analysis of its mechanical properties, and mineralogical and chemical analyses of the lagoonal mud from samples taken from the borrow pit. A year after the penetration tests were completed, Muga [1966], while measuring

TABLE III. MECHANICAL PROPERTIES OF THE SEDIMENT IN THE TEST PIT[5]

Depth (in)	0-3	4-7
Color (GSA No.)	5GY 6/1	5GY 6/1
Odor	H_2S	H_2S
Bulk Wet Density (gm/cc)	1.452	1.559
Vane Shear Strength (psi)	0.364	1.495
Remolded Strength (psi)	0.364	1.736
Sensitivity	1.0	0.9
Water Content	82.9	66.3
Specific Gravity of Solids	2.914	3.019
Dry Density (gm/cc)	0.794	0.937
Void Ratio	2.676	2.226
Porosity (%)	72.8	69.0
Saturated Void Ratio	2.416	2.002
Organic Carbon (%)	1.385	0.578
Percent Sand	6.0	2.0
Percent Silt	30.0	18.0
Percent Clay	64.0	80.0
Median Diameter (mm)	0.0020	0.0018

Note: Samples were obtained with a two and one-half inch core liner from the site where the sediment originated.

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[5] Samples collected by R. J. Smith and analyzed at the Naval Civil Engineering Laboratory in Port Hueneme.

TABLE IV. MINERALOGICAL ANALYSIS OF THE TEST PIT SEDIMENT[6]

COARSE SILT TO SAND	PERCENTAGE
Quartz	15.39
K-Feldspar	7.69
Calcite	3.36
Opal	1.47
Muscovite (illite)	11.54
	Total = 39.45 percent
ACTIVE CLAYS	
Kaolinite	16.31
Mixed Layer	29.27
	Total = 35.58 percent
INACTIVE SILT TO CLAY SIZES	
Goethite	5.83
Halite	4.53
Organic	4.41
	Total = 14.77 percent

Note: The mixed layer was composed of 67 percent montmorillonite and 33 percent chlorite. The muscovite was chiefly terrigenous (clastic) and occurred in coarse silt-sized grains. The analyses were made by a combination of x-ray diffraction, chemical, and petrographic methods. Infrared absorption analyses and differential thermal analyses were used to obtain supplemental data. The values shown are recomputed to 100 percent and are reliable to about ±15 percent.

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[6] Whelan, J. A., A Report on Mineralogy of Ocean Bottom Sediments, p. 10 unpublished report to the Naval Civil Engineering Laboratory, September, 1967.

TABLE V. CHEMICAL ANALYSIS OF TEST PIT SEDIMENT[7]

OXIDE	PERCENTAGE
SiO_2	48.34
$Al_2 0_3$	18.26
$Fe_2 0_3$	7.88
MgO	2.98
CaO	1.92
K_2O	2.74
Na_2O	3.02
H_2O	2.78
L.O.I.	9.67
Total	97.59
Surface H_2O	73.01

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[7] Whelan, op. cit., p. 8a.

TABLE VI. RANGE OF VARIATION OF TEST PIT SEDIMENT[8]

"The main feature of the soil is its highly variable properties, being both nonhomogeneous and nonisotrophic. Some of the variations are indicated below.

RANGE OF VARIATION (42 TESTS)

	MINIMUM	MAXIMUM	AVERAGE
Vane Shear Strength (psi)	0.0	1.050	0.530
Remolded Strength (psi)	0.0	0.861	0.390
Original Water Content (%)	43.5	79.6	63.5
Void Ratio	1.104	2.126	1.710
Porosity	52.5	68.0	61.9
Liquid Limit	41.0	68.0	56.1
Plastic Limit	27.5	43.4	34.2
Liquidity Index	70	255	136
Percent Sand	1.7	25.5	10.2
Percent Silt	30.8	54.4	40.5
Percent Clay	35.8	66.0	46.4

"In addition, soil samples were subjected to numerous triaxial, permeability and viscosity tests. From these tests it was determined that; (i) the yield strength of the 'soil' is approximately 0.5 psi; (ii) permeability is practically nil; (iii) cohesion, c, is almost zero; (iv) angle of internal friction is almost zero and (v) viscosity is independent of the rates of shear or deformation (i.e., rpm)."

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[8] Muga, J., Breakout Forces, p. 4, U. S. Naval Civil Engineering Laboratory Technical Note N-863, Port Hueneme, September, 1966.

break out forces in the test pit, conducted more tests to verify the mechanical properties of the sediment. Table VI is a summary of Muga's tests. It is obvious that the lagoonal mud was not uniform but characterized by variability, but a major cause of the variability was undoubtedly the result of sampling disturbances and continual reworking. Muga also stated that the mean viscosity was 300 square feet per second. This value represented a series of measurements taken with a commercial rotating-type viscometer. He did not attempt to correlate the viscosity with the vane shear strength because of the "marked variability in the soil properties". Since the sediment contained approximately 40 percent silt to sand sizes, there was certainly some angle of internal friction caused by these large sizes and this was probably the reason Muga found a high viscosity measurement. It also appeared that there were more coarse grain sizes present a year after penetration tests were conducted which indicated possible contamination with other material. For this reason Muga's values were not taken as absolutely correct, but they were included to illustrate the variability of the sediment used for the tests.

Figure 12 shows the mean shear strength profile of the sediment from 550 measurements. Although the mean strength profile is not representative of the average shear strength profile for the world's deep-ocean basins shown with a solid line, Figure 12, from Hoag [1970], it is remarkably close to the shear strength profiles of the edges

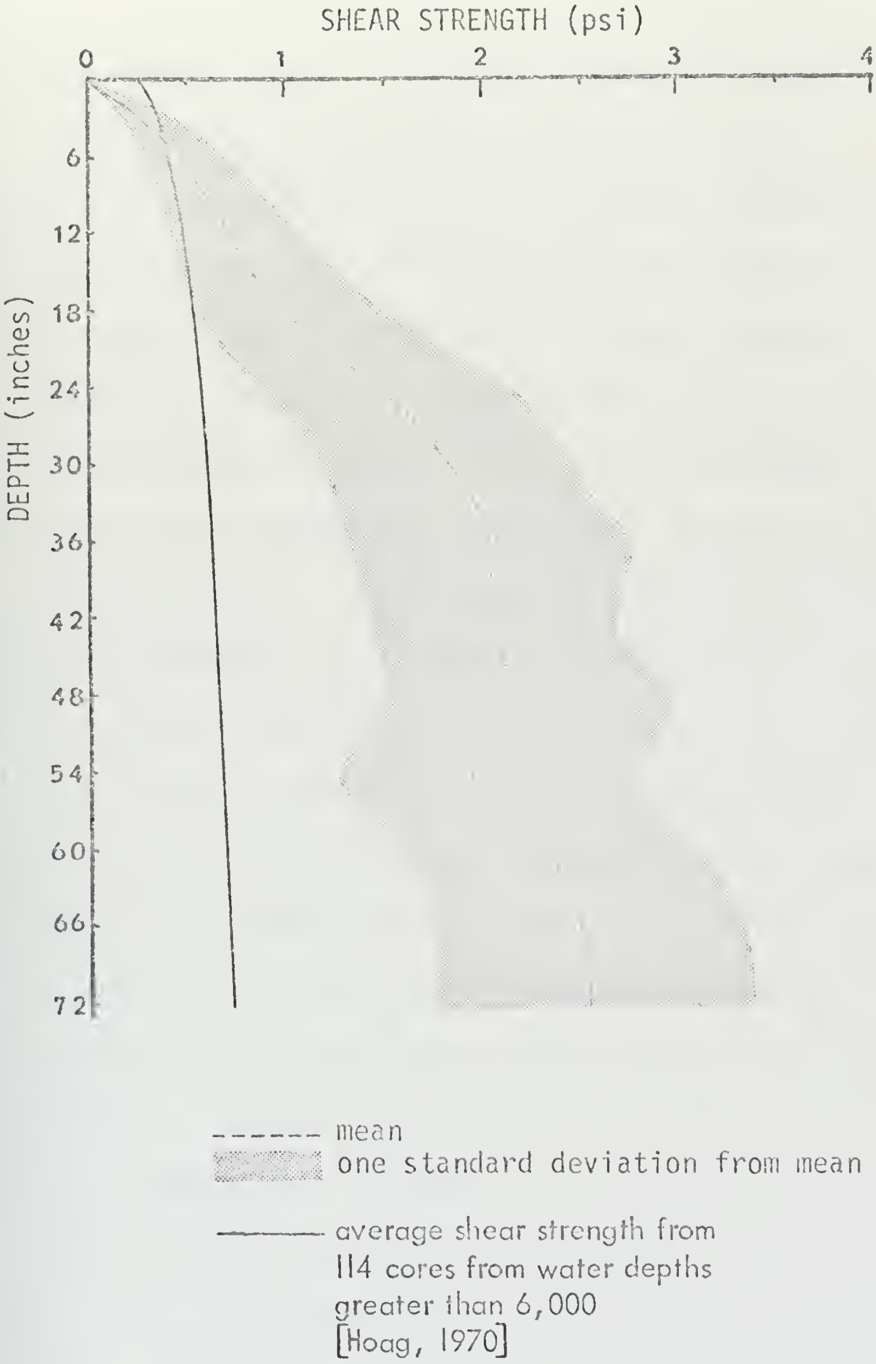
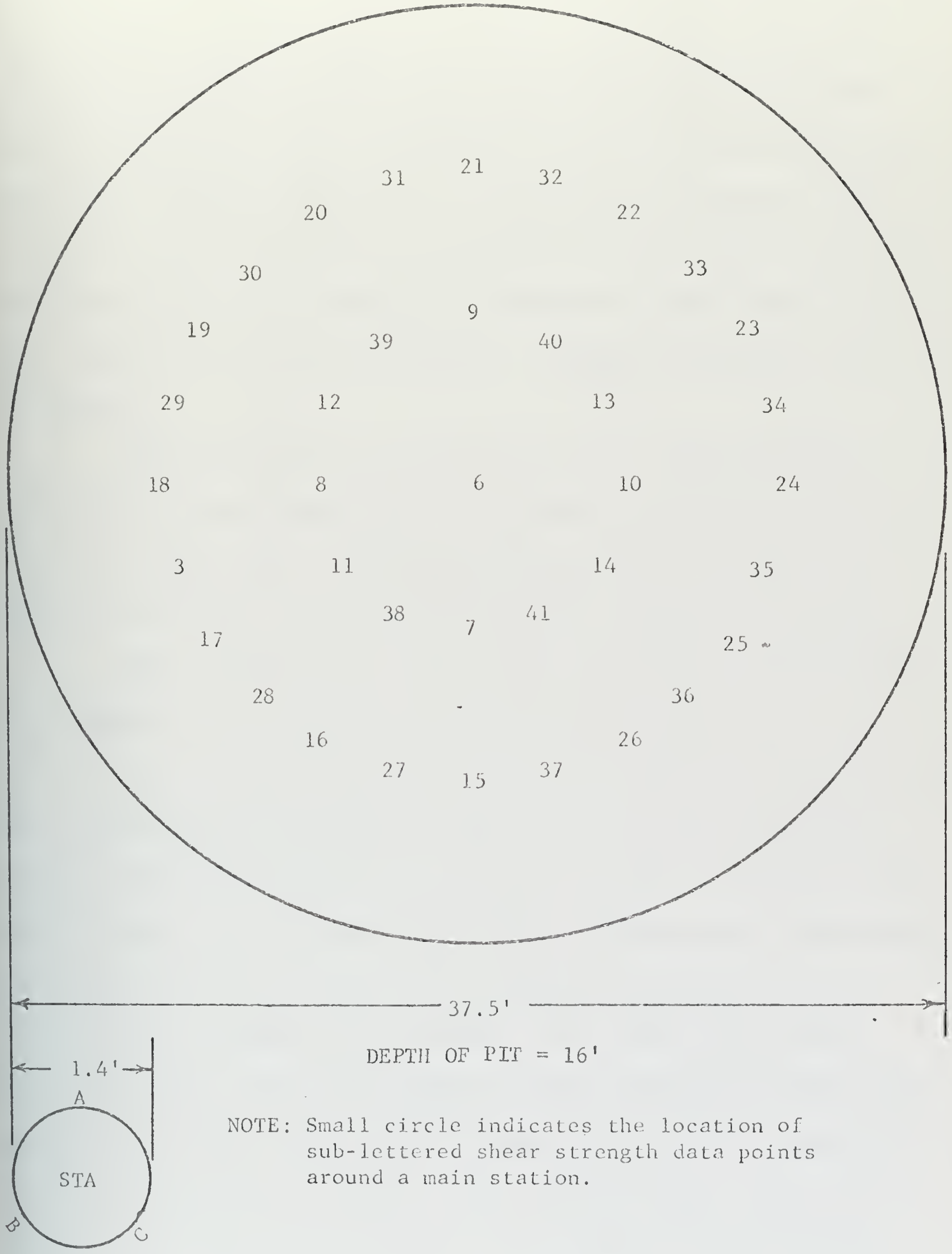


Figure 12. TEST PIT MEAN SHEAR STRENGTHS

of the Zigsbee Abyssal Plain as shown by Bryant and others [1967].

The numbering system designating the location, or station, where each penetration test was conducted is shown in Figure 13. The shear strengths at each station were taken using a two inch by five inch vane. The vane was operated by hand from a punt floating on the surface. It was driven into the sediment in six inch increments and torque applied by hand with a standard torque wrench and the maximum torque, converted to shear strength, recorded. Not all of the vane tests were conducted in the presence of an engineer and some were done by different personnel. Generally the shear strength profiles are consistently similar, with some erratic points, but there is some correlation between very erratic profiles and the date of tests, which indicated operator skill and care may have had an influence. The method of obtaining shear strength values greatly influences the value obtained according to Terzaghi [1960] and it was difficult to get consistent readings from an unstable punt with no control on the vane's rotational speed.

Other methods of determining shear strength profiles in the mud pit were considered, but rejected for the following reasons. In 1965, the existing penetrometer probes related resistance encountered to shear strength by empirical tables or graphs, and the very low strength of the mud pit was out of the empirical range. The use of these devices would have required modifications of the instruments and



DEPTH OF PIT = 16'

NOTE: Small circle indicates the location of sub-lettered shear strength data points around a main station.

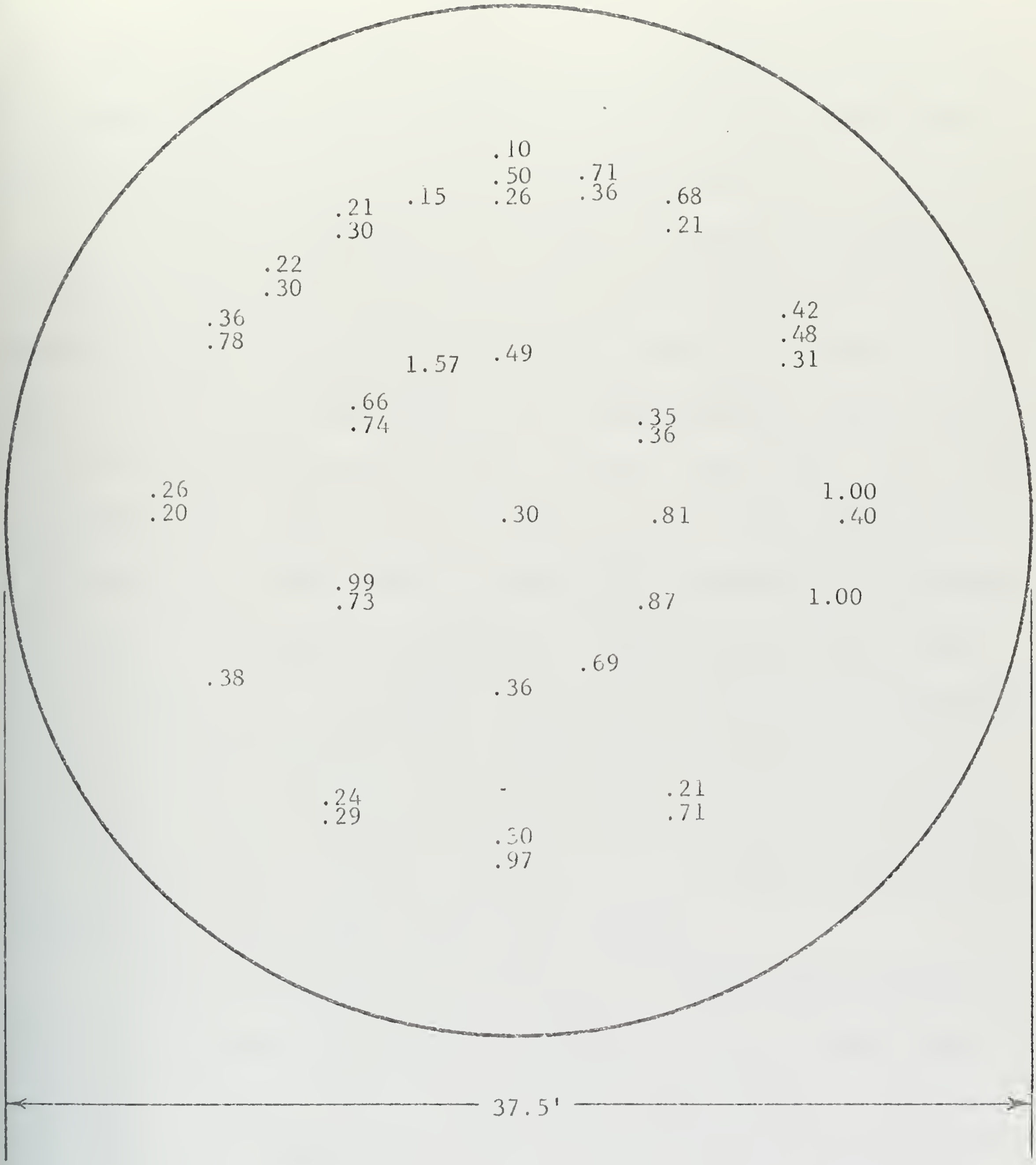
Figure 13. LOCATION OF DROP STATIONS IN THE TEST PIT

extensive testing to obtain empirical relationships. Second, the sediment in the mud pit probably had some slight but unknown angle of internal friction and the vane test measures a cohesive shear strength which is influenced by the angle of internal friction in a minor way. However, the vane test seemed the most practical test for shear strengths in cores and in-situ testing. Therefore, vane shear strengths were used exclusively to keep the results comparable to a real situation.

The horizontal variability of the observed shear strengths at six inch depths is shown in a plan view of the mud pit, Figure 14. The measurements taken on different dates in the same location also show a spread in values.

The variability of the shear strength in the mud pit was probably not random for the following reasons.

1. The huge volume of material required to fill the pit necessitated handling by large construction equipment which could have scooped up isolated chunks of material and allowed them to be placed in the pit essentially undisturbed, while most of the sediment was greatly disturbed during excavation, hauling and placement. The very high shear strengths have been attributed to the relatively small vane coming in contact with one of these hard chunks. The chunk would not necessarily affect penetration depth unless an object was dropped very close to one because the sediment was incompressible and moved as a unit. Most of the objects were large compared to the chunks or vertical distance between anomalously high observed shear strengths.



NOTE: More than one value indicates measurements
were taken on different dates.

Figure 14. SHEAR STRENGTHS AT SIX-INCH DEPTHS PLOTTED ON A PLAN VIEW OF THE TEST PIT (psi)

2. Although it was not noted in the analysis of the sediment, some organic material or foreign objects may have been present since no special precautions were taken to sieve the sediment while it was being placed.

3. The extremely low values of observed shear strength may be attributed to the method of handling the sediment after a penetration trial. The holes made by the objects and other experiments with the sediment were smoothed over, filling depressions with a shovel and rake. Then shear strengths were taken at each station and penetration drops conducted at a later time. After all the stations had been used, the procedure was repeated. Since other tests were being conducted concurrently, the hole filling and smoothing was a continuous operation. Undoubtedly some very soft material and water accumulated at the bottoms of the holes and this accounts for the anomalously low shear strengths at considerable distances below the surface.

The low sensitivity of the sediment before sampling and the continual reworking it underwent while tests were in progress, led to the conclusion that the sediment used for the tests had a sensitivity of one and that the observed in-situ shear strength of the sediment was a good representation of its actual in-situ strength, if the problems of test operator error and the anomalous points due to hard chunks or soft spots could be resolved.

Fortunately, enough data, 716 points, existed to make a statistical analysis and a mean strength profile of the

mud pit. Table VII includes a matrix of all the observed shear strengths. The anomalously high and low values were identified by eye. Since the profile should have been fairly smooth with all the reworking the sediment underwent during placement and tests, the hard and soft spots were easily selected by visual inspection. The values considered anomalous are underlined in Table VII.

The mean and standard deviation of shear strengths as a function of depth, both with and without the anomalous values, are listed in Table VIII. It should be noted that the anomalous values often cause the standard deviation to more than double. The mean shear strength profile of the mud pit and one standard deviation calculated without the anomalous points are shown in Figure 12.

At each station the anomalous points were adjusted to fit a smooth profile that generally was within one standard deviation of the mean. The adjustment process was again subjective, as the precision of the original data did not warrant a more sophisticated approach. The observed shear strengths for each station were plotted with the mean profile. Then the anomalous points were moved to fit a general smooth trend of points within one standard deviation from the mean. The figures in Appendix B illustrate the adjustment at each station and the solid line is the actual shear strength profile used by the computer solution to predict penetration depth.

The shear strength and standard deviation value at the air-sediment interface was taken to be zero, in that sea

VELOCITY ft/sec	STATION	DEPTH 6"	12"	18"	24"	30"	36"	42"	48"
SPHERE									
0.0	6	.30	.38	.78	.70	1.34	1.63	1.53	1.55
5.0	7	.36	1.04	1.03	1.56	4.00	6.53	4.17	2.16
10.0	9	.49	.77	.85	5.58	4.14	1.91	1.91	1.77
15.0	20	.30	.12	.45	2.44	2.78	2.78	5.75	3.14
20.0	26	.71	.71	3.14	1.74	2.09	2.21	2.38	2.30
5.0	15	-	.52	1.08	1.51	1.74	1.95	2.11	2.44
10.0	-	.69	.66	.52	1.39	1.56	2.05	2.44	3.01
15.0	-	-	.36	.91	1.39	1.74	1.57	2.05	2.70
20.0	-	-	1.04	1.74	2.29	1.76	4.87	2.70	2.79
HORIZONTAL CYLINDER									
0.0	23	.42	1.74	2.38	1.57	7.31	10.11	5.57	3.84
5.0	15	.97	1.25	1.08	1.88	2.04	1.96	2.38	5.22
10.0	21	.26	.68	1.24	4.18	2.44	1.76	2.33	2.75
15.0	16	.29	.52	.17	.29	.76	2.16	1.74	1.76
20.0	22	.68	.73	1.74	2.16	2.45	3.86	2.58	3.84
20.0	12	1.74	2.18	2.78	1.22	1.01	1.74	1.30	.69
CYLINDER ON END									
5.0	-	-	.61	1.39	2.09	2.44	7.27	5.15	-
10.0	-	.37	.54	1.04	1.36	2.44	2.78	5.21	4.80
15.0	-	.52	.78	1.91	3.82	2.38	2.01	2.11	1.97
20.0	-	.69	1.81	1.43	1.06	1.97	1.57	1.65	1.76
0.0	22	.21	.35	.52	1.10	3.12	2.78	2.56	3.10
5.0	14	.87	1.04	1.04	1.41	1.13	1.48	1.87	1.76
10.0	16	.24	.33	.71	.87	1.74	1.74	1.79	1.81
15.0	12	.66	1.76	2.21	.87	.83	1.57	1.43	.42
15.0	21	1.03	.75	1.18	1.37	1.53	2.26	1.91	2.02
20.0	11	.73	1.27	.99	.52	1.52	1.91	1.39	3.96

NOTE: (1) A SINGLE DASH INDICATES MISSING DATA

(2) UNDERLINED VALUES WERE CONSIDERED ANOMALOUS

Table VII. SEDIMENT VANE SHEAR STRENGTHS IN THE TEST PIT

VELOCITY ft/sec	STATION	DEPTH 6"	12"	18"	24"	30"	36"	42"	48"				
CYLINDER ON END (CONT)													
5.0	20	.21	.31	.31	1.44	1.44	2.44	5.54	2.44				
10.0	25	.21	.57	1.46	2.11	2.05	2.07	2.09	6.26				
15.0	19	.36	.45	.40	1.22	1.39	1.74	2.35	4.45				
20.0	35	1.81	1.04	1.39	2.26	2.32	3.50	2.79	1.91				
CUBE													
5.0	-	1.01	1.04	1.76	.87	1.23	1.53	.56	.35				
10.0	-	1.06	.71	1.01	2.68	6.92	2.10	2.38	2.10				
15.0	-	.61	.72	3.48	2.97	1.88	1.74	1.55	1.60				
20.0	-	.75	1.29	.52	.66	2.83	5.07	6.95	3.04				
RECTANGLE													
0.0	24	1.39	.71	1.04	.52	1.74	2.12	2.78	2.87				
5.0	13	.35	1.02	1.37	2.68	2,99	5.87	3.65	2.77				
10.0	11	.99	.68	.71	1.70	1.74	2.07	1.95	3.13				
15.0	17	.38	.69	.69	1.56	2.00	3.48	5.93	4.35				
15.0	19	.78	.33	.35	.69	1.74	6.10	4.86	3.91				
20.0	18	.26	.35	1.31	.78	1.56	3.30	4.52	2.44				
CONE										54"	60"	66"	72"
0.0	23	.31	.35	.52	.75	.95	2.78	1.71	2.61	3.36	2.61	2.70	2.96
0.0	a	.66	1.30	5.45	5.35	2.60	1.74	2.44	2.60	2.66	3.70	2.69	5.70
0.0	b	.29	.40	.68	.99	1.53	1.82	5.78	2.59	4.52	5.30	2.40	2.82
0.0	c	.66	.71	1.50	1.48	2.35	2.92	4.95	2.28	4.70	2.75	2.21	5.70
5.0	13	.36	.29	.71	2.12	1.36	3.35	3.33	2.82	1.95	1.79	1.90	1.88
"	a	.76	1.22	.69	1.38	8.60	9.99	2.65	2.35	1.60	1.32	1.62	5.21

TABLE VII. (CONTINUED) SEDIMENT VANE SHEAR STRENGTHS IN THE TEST PIT

VELOCITY ft/sec	STATION	DEPTH											
		6"	12"	18"	24"	30"	36"	42"	48"	54"	60"	66"	72"
CONE (CONT)													
5.0	b	1.18	.54	.49	3.11	2.49	1.79	1.72	2.08	1.44	1.31	1.28	1.28
"	c	.95	.67	.82	1.88	3.03	3.15	2.96	1.80	2.57	2.12	1.62	2.10
10.0	30	.22	.15	.31	3.25	7.50	6.30	6.90	4.92	8.70	3.65	3.01	2.49
"	a	.17	.35	.66	2.28	4.78	5.00	8.46	5.80	6.11	5.45	3.27	3.29
"	b	.45	.19	.22	.34	.75	3.45	8.32	9.46	7.64	4.63	2.92	4.93
"	c	.33	.24	.69	2.33	2.19	2.49	4.38	3.81	2.92	3.15	3.67	3.59
15.0	31	.15	.15	.20	.55	1.14	1.68	2.45	1.79	7.26	3.76	5.79	5.35
"	a	.10	.15	.41	1.20	2.26	1.60	1.74	5.43	8.93	9.90	4.47	4.85
"	b	.28	.15	.17	.24	.80	1.32	1.11	2.71	2.40	3.80	3.38	4.01
"	c	.70	.43	.33	1.04	2.89	2.07	4.12	5.91	6.66	5.46	5.02	3.57
20.0	32	.36	.38	.76	1.32	1.60	6.32	5.70	2.60	2.23	2.36	2.54	5.80
"	a	.43	.73	1.03	2.16	2.30	5.35	2.34	3.01	2.64	2.85	3.72	3.80
"	b	.66	1.01	.87	7.20	4.94	2.82	2.17	1.97	2.54	2.80	2.74	4.13
"	c	1.39	.54	1.91	2.86	2.97	3.59	1.60	1.76	3.34	3.45	2.66	3.16
OTHER MEASUREMENTS													
	39	1.57	1.22	1.13	.87	.70	.68	.68	1.57	2.61	2.18	3.27	1.94
	41	.69	.73	.73	1.57	1.58	1.57	5.90	7.65	2.36	2.70	2.65	2.78
	-	.67	.60	.45	.90	1.40	1.56	1.75	1.50	1.25	1.90	1.75	1.60
	18	.20	.45	.85	1.05	1.05	1.45	1.65	1.40	1.25	1.20	1.15	1.30
	a	.40	.65	.65	.75	.85	.85	.75	.90	.90	.20	.35	.60
	b	.60	1.20	.85	.85	1.00	1.00	1.10	1.20	.90	.70	.70	1.00
	c	.80	1.20	1.85	1.70	1.15	1.10	1.15	1.30	1.15	1.00	3.20	1.70
	21	.10	.15	.35	.60	1.00	1.05	1.00	.80	.60	.40	.90	2.50
	a	.30	.70	1.10	1.20	1.00	1.05	1.15	.85	.95	1.30	1.90	2.90
	b	.40	.85	1.20	1.60	2.05	1.50	1.10	.95	1.10	1.30	2.15	2.90
	c	.60	1.05	1.25	1.65	2.25	1.65	1.25	1.20	1.45	1.75	2.60	3.25
	24	.40	1.05	.80	.90	1.05	.80	.80	1.35	1.40	.90	.75	.90
	a	.60	1.40	1.20	1.15	1.20	1.20	1.20	1.50	1.60	1.80	1.35	1.50
	b	1.10	1.75	2.15	2.05	1.35	1.75	1.60	1.60	1.75	2.05	1.95	2.20

TABLE VII. (CONTINUED) SEDIMENT VANE SHEAR STRENGTHS IN THE TEST PIT

TABLE VIII. MEAN SHEAR STRENGTHS AND STANDARD DEVIATIONS OF TEST PIT.

DEPTH	MEAN SHEAR STRENGTHS		ONE STANDARD DEVIATION	
(in)	(psi)		(psi)	
6"	$.50_{(55)}$	$.60_{(69)}$	.23	.38
12"	$.73_{(60)}$	$.75_{(73)}$	.32	.44
18"	$.99_{(61)}$	$1.11_{(73)}$	.47	.84
24"	$1.50_{(60)}$	$1.72_{(73)}$	.63	1.21
30"	$1.80_{(60)}$	$2.22_{(73)}$	.62	1.57
36"	$2.03_{(56)}$	$2.77_{(73)}$	.70	1.94
42"	$1.98_{(50)}$	$2.87_{(73)}$	.60	1.87
48"	$2.20_{(57)}$	$2.71_{(72)}$	.74	1.60
54"	$1.93_{(25)}$	$3.40_{(34)}$	.75	1.96
60"	$2.34_{(25)}$	$2.69_{(34)}$	.71	1.81
66"	$2.52_{(28)}$	$2.47_{(34)}$	.82	1.21
72"	$2.52_{(24)}$	$3.04_{(34)}$	.87	1.49

Note: The first columns under the shear strengths and standard deviations are values computed with the anomalous points discarded. The second columns are values computed with all the data points. The subscripts in parenthesis are the number of data points.

water was continually added to the test pit to offset evaporation losses and the top of the pit was continually being reworked by raking. In general, a virgin undisturbed sediment should have a finite strength at the surface.

C. RESULTS

Table IX summarizes the observed penetration depths, the predicted depths, and tabulates the difference between observed and predicted. A numerical analysis of the differences between observed and predicted depths was not made because, with few exceptions, the method developed accurately predicted the penetration depth within the experimental uncertainties of depth measurement and shear strength accuracy. The method overestimated penetration 17 times and underestimated penetration 22 times. The largest differences were underestimates of penetration. In all cases of differences greater than four inches, the prediction had to rely on an adjusted shear strength. This indicated a problem with measuring the shear strength at that station and implied the presence of a soft pocket in the sediment. The large discrepancies also occurred with impact velocities of five feet per second.

Table X sets forth the penetration data along with notes taken from movies of the tests. The time-to-penetrate was observed by counting the frames of the movie film from object impact until all downward motion had ceased. The rebound time was also observed by counting movie frames. The rebound distance was estimated from the pictures and is believed

Table IX. SUMMARY OF RESULTS

OBJECT VELOCITY (ft/sec)	PENETRATION OBSERVED (in)	PENETRATION PREDICTED (in)	DIFFERENCE (in)
SPHERE (wt. = 561 lbs)			
0.0	9.5"	10.7"	+ 1.2"
5.0	13.5"	12.1"	- 1.3"
10.0	14.0"	14.0"	0.0"
15.0	24.2"	24.5"	+ 0.3"
20.0	20.0"	20.5"	+ 0.5"
5.0	16.0"	11.5"	- 4.5"
10.0	16.0"	12.1"	- 3.9"
15.0	19.0"	23.0"	+ 4.0"
20.0	19.5"	20.4"	+ 0.9"
HORIZONTAL CYLINDER (wt. = 540 lbs)			
0.0	5.5"	6.0"	+ 0.5"
5.0	11.5"	7.5"	- 4.0"
10.0	13.0"	13.8"	+ 0.8"
15.0	17.0"	17.0"	0.0"
20.0	16.0"	15.9"	- 0.1"
20.0	14.7"	14.7"	0.0"
CYLINDER ON FLAT END (wt. = 540 lbs)			
5.0	14.0"	8.7"	- 5.3"
10.0	15.5"	12.8"	- 2.7"
15.0	15.0"	14.2"	- 0.8"
20.0	-----	16.2"	-----
0.0	8.0"	8.4"	+ 0.4"
5.0	4.2"	4.4"	+ 0.2"
10.0	18.0"	16.0"	- 2.0"
15.0	14.0"	12.7"	- 1.3"
15.0	18.0"	14.6"	- 3.4"
20.0	19.0"	16.8"	- 2.2"

TABLE IX. (CONTINUED) SUMMARY OF RESULTS

OBJECT VELOCITY (ft/sec)	PENETRATION OBSERVED (in)	PENETRATION PREDICTED (in)	DIFFERENCE (in)
CYLINDER ON FLAT END (wt. = 561 lbs)			
5.0	-----	12.6"	-----
10.0	14.0"	14.0"	0.0"
15.0	18.5"	20.4"	+1.9"
20.0	13.5"	16.1"	+2.6"
CUBE (wt. = 702 lbs)			
0.0	4.5"	3.7"	-0.8"
5.0	5.7"	4.4"	-1.3"
10.0	8.5"	9.7"	+1.2"
15.0	13.0"	12.8"	-0.2"
20.0	17.0"	14.9"	-2.1"
RECTANGLE (parallelopiped, wt. = 1014 lbs)			
0.0	3.0"	3.2"	+0.2"
5.0	5.0"	7.0"	+2.0"
10.0	9.2"	9.4"	+0.2"
15.0	14.8"	14.7"	-0.1"
15.0	15.5"	19.0"	+3.5"
20.0	21.6"	20.1"	-1.5"
CONE (wt. = 1127 lbs)			
0.0	55.0"	50.0"	-5.0"
5.0	53.5"	51.0"	-2.5"
10.0	49.5"	54.0"	+4.5"
15.0	65.0"	64.0"	-1.0"
20.0	62.5"	59.0"	-3.5"

accurate to one inch. Penetration depth refers to the object's final resting position and did not exclude the rebound distance. The percent of ultimate bearing capacity was calculated as; the ultimate bearing capacity of the sediment at the depth the object came to rest, divided by the actual force applied to the sediment by the object at its final resting position. The shear strength adjusted column indicates whether or not an anomalous shear strength value was adjusted which directly affected the calculations of penetration prediction.

The time-to-penetrate measurement was done in an inexact manner, but is remarkably constant when the range of velocities and different object shapes are considered. Its relative constancy in relation to the other parameters may indicate that it is related to a unique basic property of the sediment. Schmid [1966] observed the same phenomena when testing small penetrometers with different impact velocities.

The rebound time and distance were very difficult to estimate due to the short duration and fact that splatter sometimes partially obscured the object. Some of the rebound of the object, and apparent elastic behavior of the sediment was originally thought to be caused by a buoyancy effect. However the cavity formed by penetration did not collapse until rebound was over and the object was essentially at rest. Subjectively it appears that rebound is a function of an elastic property of the sediment.

The percent of ultimate bearing capacity that was reached by the different objects seems to relate to impact velocity. In all the penetration tests the objects were left in place for at least 24 hours and in some cases up to eight days and then checked to see if they had settled further into the sediment. No further settlement was observed in any case. At an impact velocity of five feet-per-second the objects consistantly penetrated to a level where 300 percent of the ultimate bearing capacity was available to support the object. This implies that a structure being emplaced by a free-fall technique would only require a velocity of five feet-per-second to generate the safety factor of three recommended in soil mechanics in a situation where the ultimate bearing capacity equation is used.

As observed in the movies, any air entrapped under the object had negligible effect on either rebound or penetration depth. Rounded objects such as the sphere and horizontal cylinder did not behave differently from the flat sided objects that did entrap some air.

Cratering and pile up of the sediment was slight. In all cases, even with the rectangular parallelepiped impacting at 20 feet per second, the crater lip was less than 2 inches high. The sediment moved laterally away from the objects and not up.

Table X. NOTES FROM PENETRATION TESTS

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT, 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	SPHERE NOTES FROM MOVIES OF THE TESTS
0.0	10.7	+1.2	15	.25	½	.13	240	no	----
5.0	12.2	-1.3	15	.25	1	.13	325	no	The sediment moved with a horizontal motion five feet from the drop position.
10.0	14.0	0.0	15	.22	1	.16	493	no	The sphere rotated during and after rebound.
15.0	24.5	+0.3	15	.22	1	.19	478	yes	A neat crater with a small lip was formed around the sphere. The sediment moved horizontally away from the sphere.
20.0	20.5	+0.5	15	.17	2	.19	795	no	The sediment was observed to move horizontally away and up slightly during penetration. It moved toward the sphere as the sphere came to rest.
5.0	11.5	-4.5	13	.28	½	.10	336	yes	The shear strength at six inches was not recorded. The sphere went straight in forming a small crater.
10.0	12.1	-3.9	13	.22	½	.12	590	no	-----
15.0	23.0	+4.0	13	.22	1	.10	670	yes	The shear strength at six inches was not recorded. A small crater was formed with the sediment having a peeled back appearance at the rim.
20.0	20.4	-0.9	13	.18	2½	.12	1060	yes	The shear strength at six inches was not recorded. The crater slumped in after the sphere came to rest.

TABLE X. (CONTINUED)

HORIZONTAL CYLINDER

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT, 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	NOTES FROM MOVIES OF THE TESTS
0.0	6.0	+0.5	14	.22	0	-	206	no	The cylinder went straight in with little splatter and rotated about its axis after maximum penetration.
5.0	7.5	-4.0	14	.22	1	.10	317	yes	The cylinder went straight in but only one end rebounded. At rest one end was three inches lower than the other.
10.0	13.8	+0.8	14	.22	2½	.22	495	no	The cylinder went straight in and rebounded straight up with a small amount of splatter. Four feet away from the cylinder the sediment moved horizontally.
15.0	17.0	0.0	14	.22	4	.25	607	no	The cylinder went straight in but one end penetrated four inches more than the other. The rebound was at an angle. A definite horizontal motion of the sediment was observed up to six feet away from the cylinder.
20.0	15.9	-0.1	14	.22	-	.19	848	no	One end penetrated seven inches more than the other. Not much splatter was observed. A crater was made but it slid in around the cylinder during rebound.
20.0	14.7	0.0	14	.19	3	.22	1020	yes	Cylinder went straight in and rebounded straight up.
									In all the tests the cylinder rotated and wobbled at the maximum penetration depth as if it was floating in a liquid.

TABLE X. (CONTINUED)

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT, 1965	TIME TO PENETRATE (sec)	REBOUND D DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	CYLINDER ON FLAT END (wt. -540 lbs) NOTES FROM MOVIES OF THE TESTS
5.0	8.7	-5.3	10	---	-	---	268	yes	Only before and after pictures were available. The shear strength at six inches was not recorded.
10.0	12.8	-2.7	10	---	-	---	348	no	Only before and after pictures were available.
15.0	14.2	-0.8	10	.19	1	.12	580	no	Cylinder went straight in and rebounded straight up.
20.0	16.2	----	10	.22	1	.12	750	yes	The cylinder was swinging when it was dropped and was canted about six degrees on impact. It continued to tip completely over as it penetrated and came to rest in an almost horizontal position with a little over one half its volume submerged. It was impossible to estimate a penetration depth.
0.0	8.4	+0.4	15	.25	-	---	168	no	The movies showed three different trials at zero velocity. In each case the cylinder tipped over after reaching its maximum penetration depth. The observed penetration was estimated from the movies to be eight inches in all three cases.
5.0	4.4	-0.2	15	.19	½	.12	319	no	----
10.0	16.0	-2.0	15	.22	-	.19	369	no	The cylinder went straight in to about 14 inches then tipped on rebound. One side penetrated to 22 inches and the other to 14 inches.

TABLE X. (CONTINUED)

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT. 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	CYLINDER ON FLAT END (wt. 540 lbs) NOTES FROM MOVIES OF THE TESTS
15.0	12.7	-1.3	15	.19	1	.12	583	yes	The cylinder went straight in to about 14 inches then tipped on rebound. One side penetrated to 23 inches and the other to 11 inches. Penetration distance was estimated as 14 inches.
15.0	14.6	-3.4	15	.22	-	.19	534	yes	----
20.0	16.8	-2.2	15	.19	1½	.16	596	yes	Cylinder went straight in and tilted on rebound. In the final resting position one side penetrated to 23 inches and the other to 18.
									CYLINDER ON FLAT END (wt. 561 lbs)
5.0	12.6	----	20	.22	-	---	206	no	The movies showed two trials. In both cases the cylinder tipped completely over making it impossible to record an accurate penetration depth.
10.0	14.0	0.0	20	.22	-	---	475	no	Cylinder went straight in and tilted on rebound.
15.0	20.4	+1.9	20	.22	-	---	443	no	Cylinder went straight in forming a small crater. There was about one inch between the cylinder and the wall of the crater which was filled with the liquid splatter.
20.0	16.1	+2.6	20	.19	-	.10	735	yes	----

TABLE X. (CONTINUED)

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT. 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	CUBE NOTES FROM MOVIES OF THE TESTS
0.0	3.7	-0.8	13	.22	-	---	157	yes	The shear strengths were not recorded for this test, therefore a shear strength profile similar to the mean for the mud pit was used. It was biased toward the other profiles determined on the 13 September. Air was trapped underneath the cube and it continued to jet out for about one second after the cube came to rest.
5.0	4.4	-1.3	13	.22	1	.06	332	yes	The cube went straight in and rebounded straight up. There was no entrapped air.
10.0	9.7	+1.2	13	.22	½	.06	412	yes	----
15.0	12.8	-0.2	13	.22	2	.12	507	no	The cube entered the sediment at a slight angle. One side penetrated five inches below the other. Entrapped air vented as the maximum depth was reached. The cube slid about two inches horizontally during the penetration.
20.0	14.9	-2.1	13	.22	-	.12	638	yes	The cube penetrated straight in and rebounded straight up but canted about two inches after resting. A crater was formed with the sediment raised slightly above the mean surface of the mud pit. The rise was visible three feet from the cube.

TABLE X. (CONTINUED)

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	RECTANGLE NOTES FROM MOVIES OF THE TESTS
0.0	3.2	+0.2	14	.22	-	0.0	154	yes	The rectangle tilted about one inch and slid sideways about two inches during penetration.
5.0	7.0	+2.0	14	.22	½	.12	366	no	----
10.0	9.4	+0.2	14	.22	½	.19	405	yes	The rectangle penetrated straight in until one half the total depth was reached then it tilted with one corner coming to rest three inches below the opposite corner. The sediment formed a crater as usual and moved horizontally away from the rectangle during the penetration.
15.0	14.7	-0.1	14	.22	1	.19	512	no	The rectangle entered straight then at a penetration depth of about eight inches one side dipped about six inches. The rebound further tilted the rectangle and at rest one corner was nine inches lower than the opposite corner.
15.0	19.0	+3.5	14	.25	1½	.16	332	yes	The rectangle penetrated straight in and rebounded straight up. The sediment moved horizontally ten feet distant from the rectangle as it penetrated.
20.0	20.1	-1.5	14	.22	-	.22	708	yes	At a distance of eight feet the sediment moved up then away from the rectangle. The volume of splatter from the impact was estimated to be less than ten percent of the crater volume.

TABLE X. (CONTINUED)

CONE

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT. 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	
0.0	50.0	-5.0	23	---	-	---	372	yes	The shear strength profile is the average of four sets of data from the location where the cones were dropped. No motion pictures were available for the cone tests.
5.0	51.0	-2.5	23	---	-	---	490	yes	"
10.0	54.0	+4.5	24	---	-	---	645	yes	"
15.0	64.0	-1.0	24	---	-	---	746	yes	"
20.0	59.0	-3.5	24	---	-	---	801	yes	"

IV. CONCLUSIONS AND RECOMMENDATIONS

A rational, phenomenological, theory has been applied to the problems of free-fall penetration into a simulated deep-sea sediment. The theory correlated well with full scale tests. A more complete solution will probably only be available after more is understood about the mechanical properties and dynamic behavior of deep-sea sediment.

A. CONCLUSIONS

The method predicts the penetration of free-falling objects into weak, saturated sediments for an air-to-sediment case within the accuracy of the present state-of-the-art techniques for measuring the sediment mechanical properties. It should work equally well in a water-to-sediment case with some modifications.

The impact duration time, from the instant of contact until the object comes to rest, was observed to be relatively constant and may be a unique property of the dynamic behavior of a sediment type. The duration time was relatively constant even though the penetration distance changed, the object shapes were different, and the kinetic energy of the falling objects ranged from 0 to 5,000 foot-pounds.

The method may be used with larger, heavier objects but caution must be used in extending the method for use with smaller objects since viscous drag and surface adhesion effects may be important for smaller masses.

At high impact velocities the effects of added mass and form drag cannot be neglected in computing penetration depth. The accuracy of the constants and variables in the standard bearing capacity equation have the most control over predicted penetration depths.

B. RECOMMENDATIONS

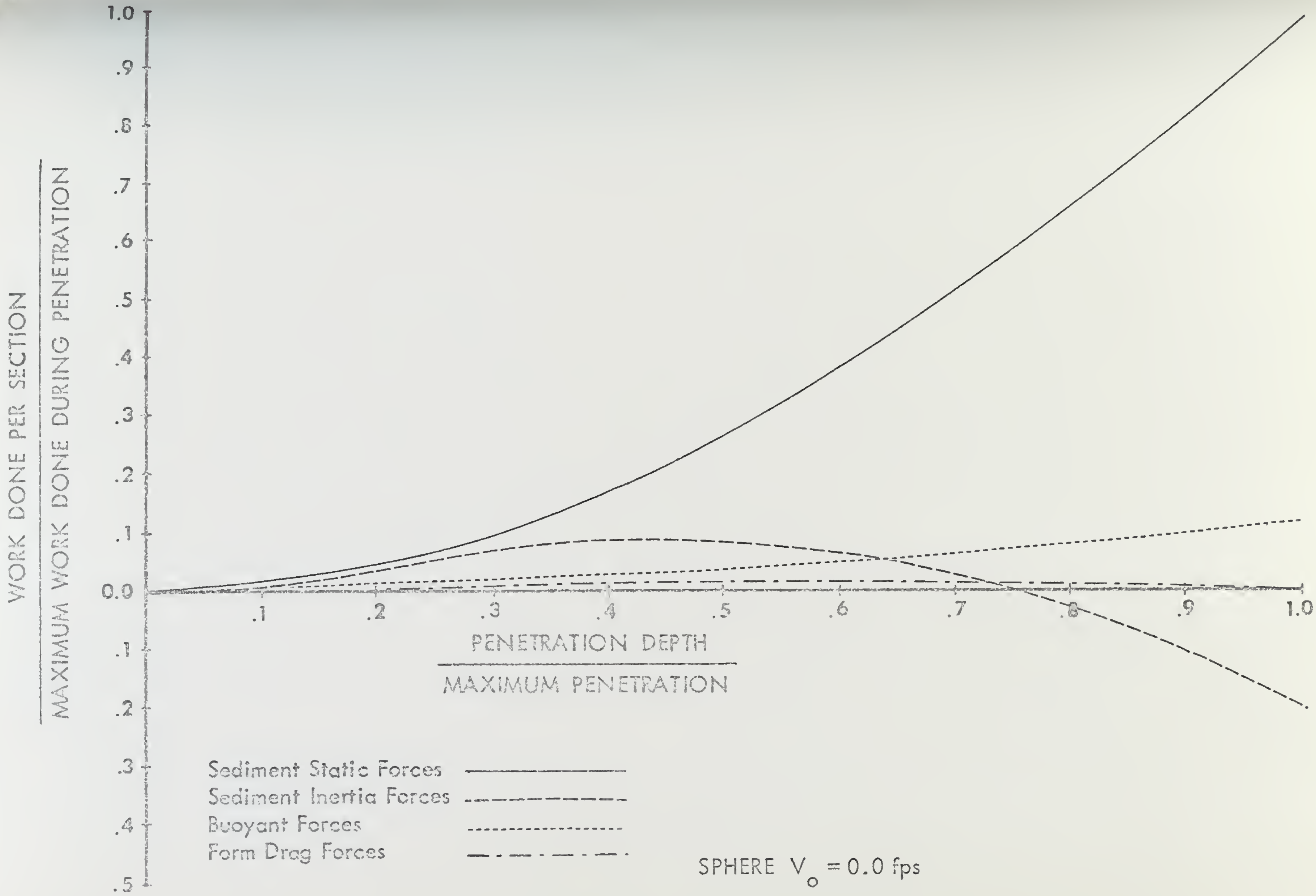
The method should be experimentally verified by full scale tests at sea or by controlled tests in a large tank ashore using a uniform sediment whose mechanical properties are known. Experiments of the scale needed would require a major effort but could include investigations into other unknown areas such as the free-fall attitude and stability of various shapes in water, the verification of terminal velocities of free-falling unstabilized objects in a water column and the study of breakout forces and salvage methods required to retrieve the objects.

Whenever an object is recovered from the deep-ocean floor every effort should be made to obtain photographs of the object. The sediment around the object should be extensively sampled and completely analyzed to allow verification of this method of predicting penetration depth.

APPENDIX A

FORCES ON OBJECTS PENETRATING A TYPICAL SEDIMENT

Appendix A includes a set of curves which qualitatively illustrate the relative influence of each force in the penetration equation. They were obtained by using the sediment shear strength profile typical of the world's deep-ocean basins as determined by Hoag [1970] and shown in Figure 13. The curves are normalized for depth of penetration on the abcissa and the maximum force encountered on the ordinate. Time is independent of the calculations and the shape of the curve near the origin is largely a function of the iteration interval.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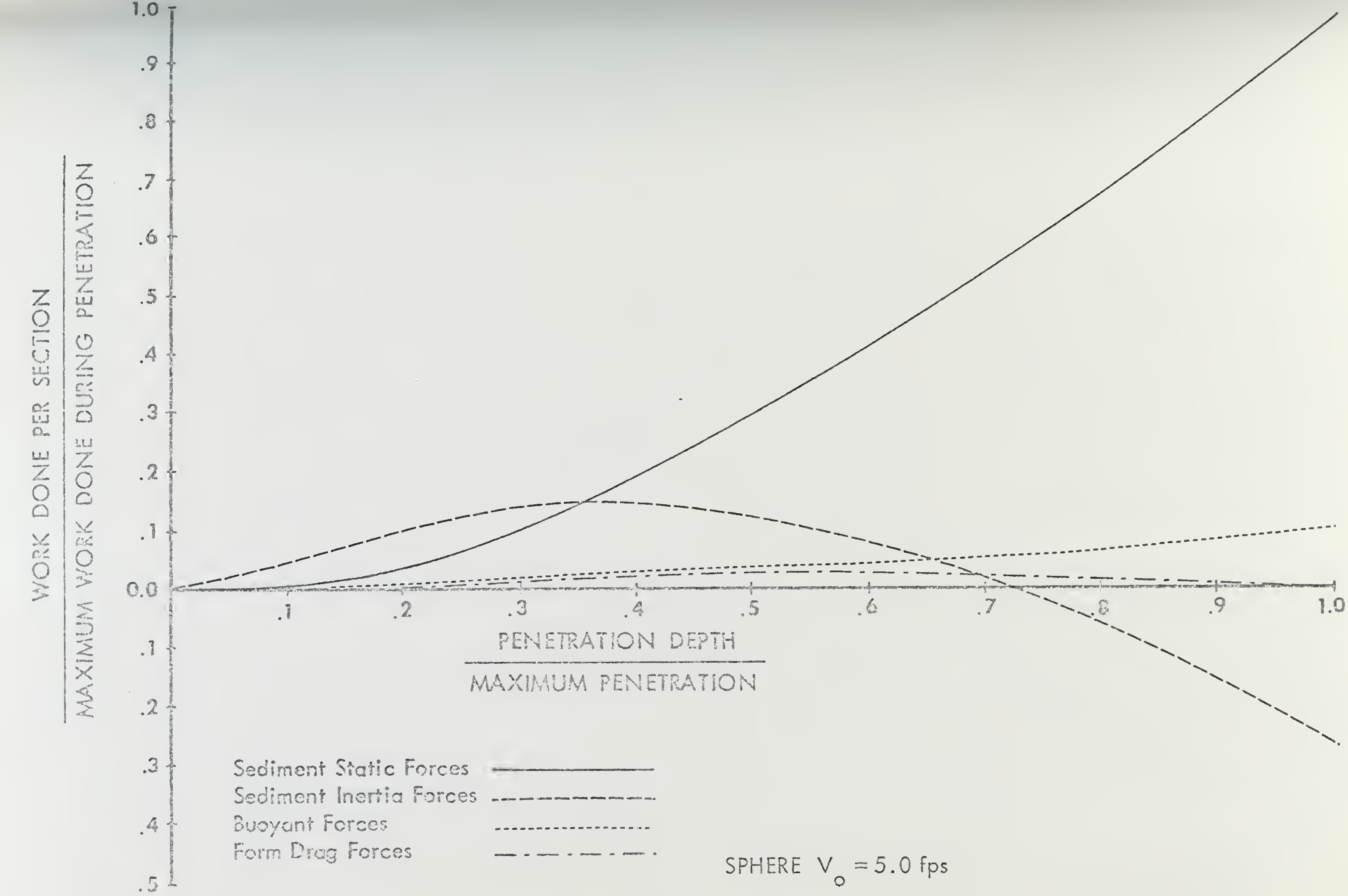
Form Drag Forces
SPHERE $V_o = 0.0$ fps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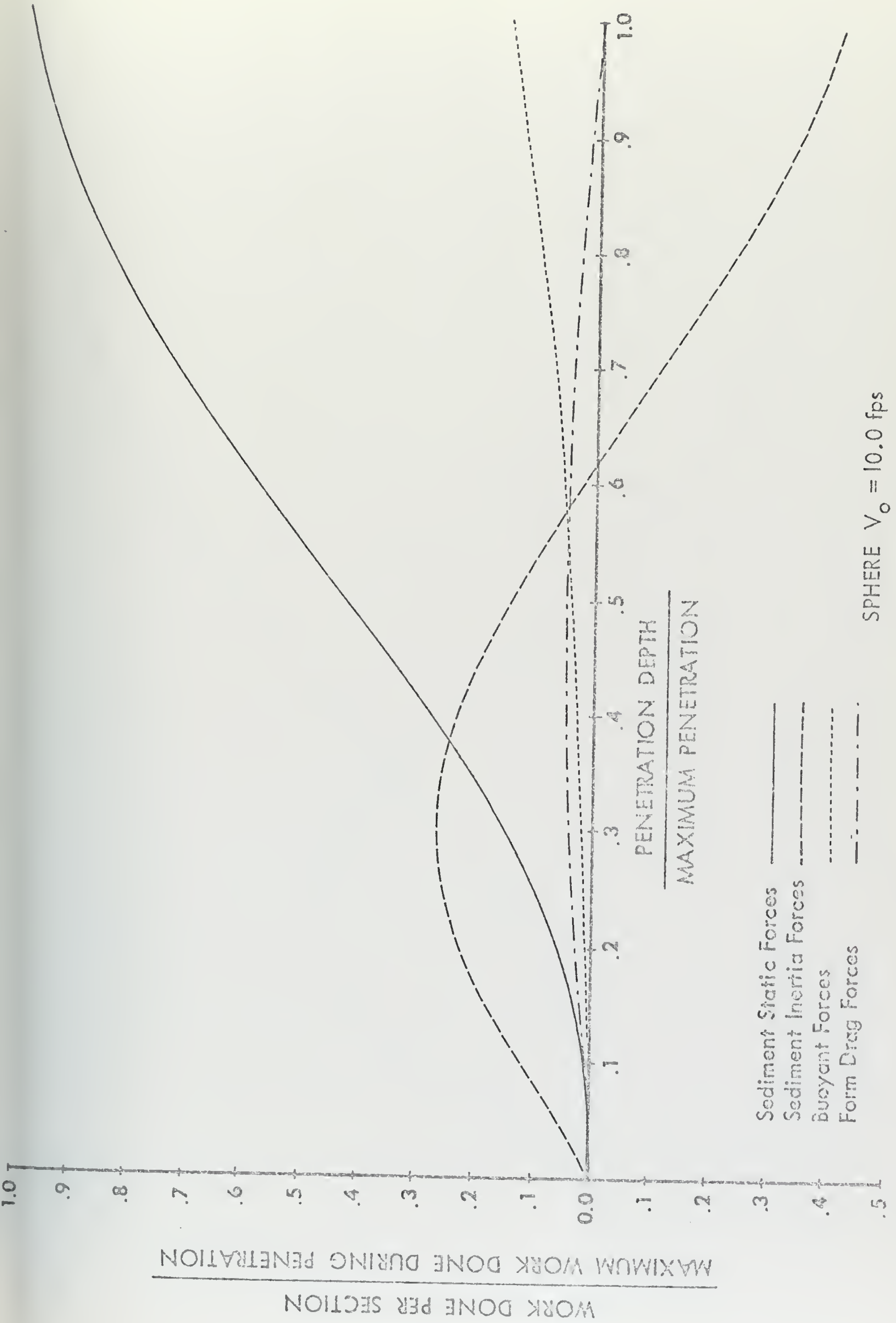
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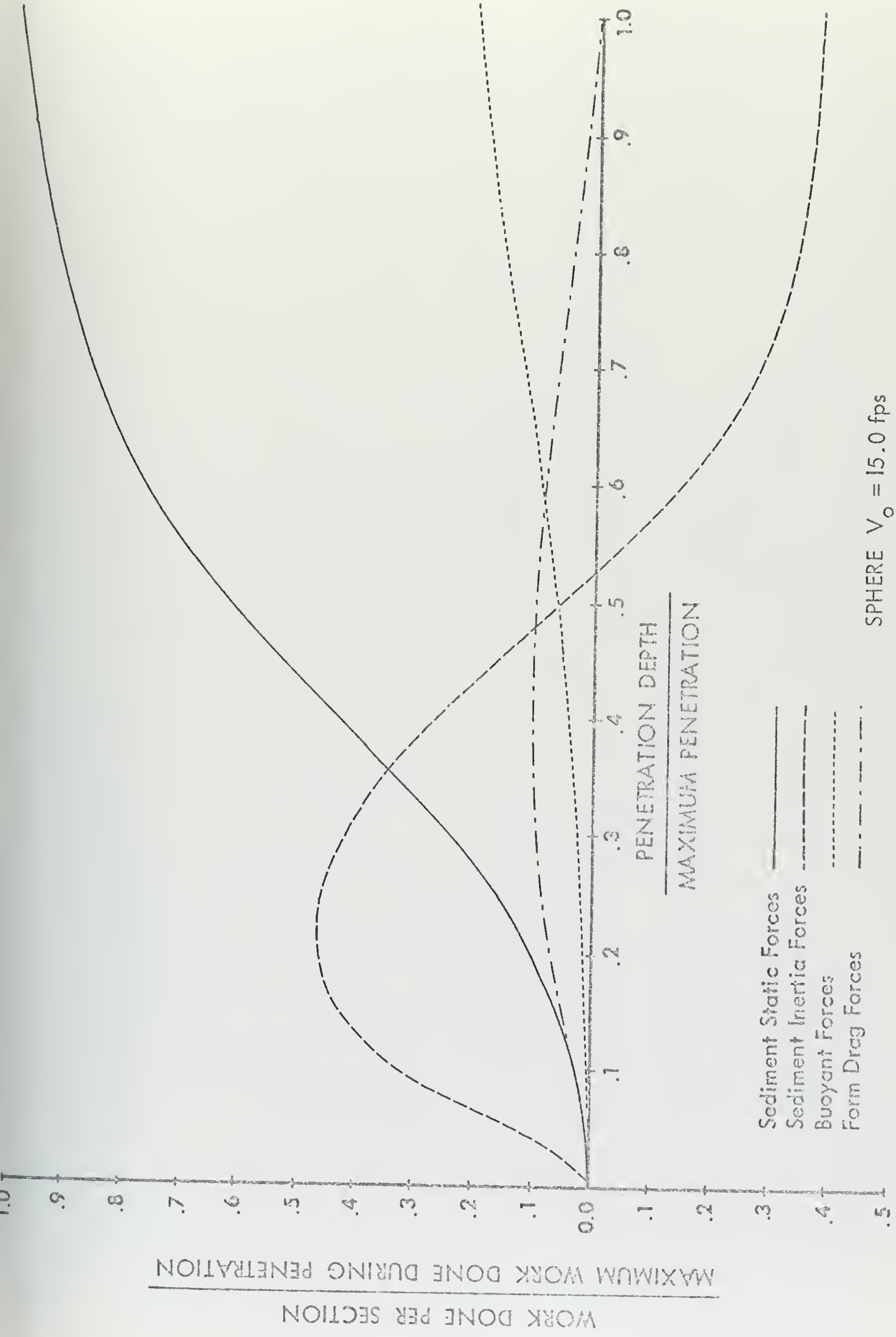
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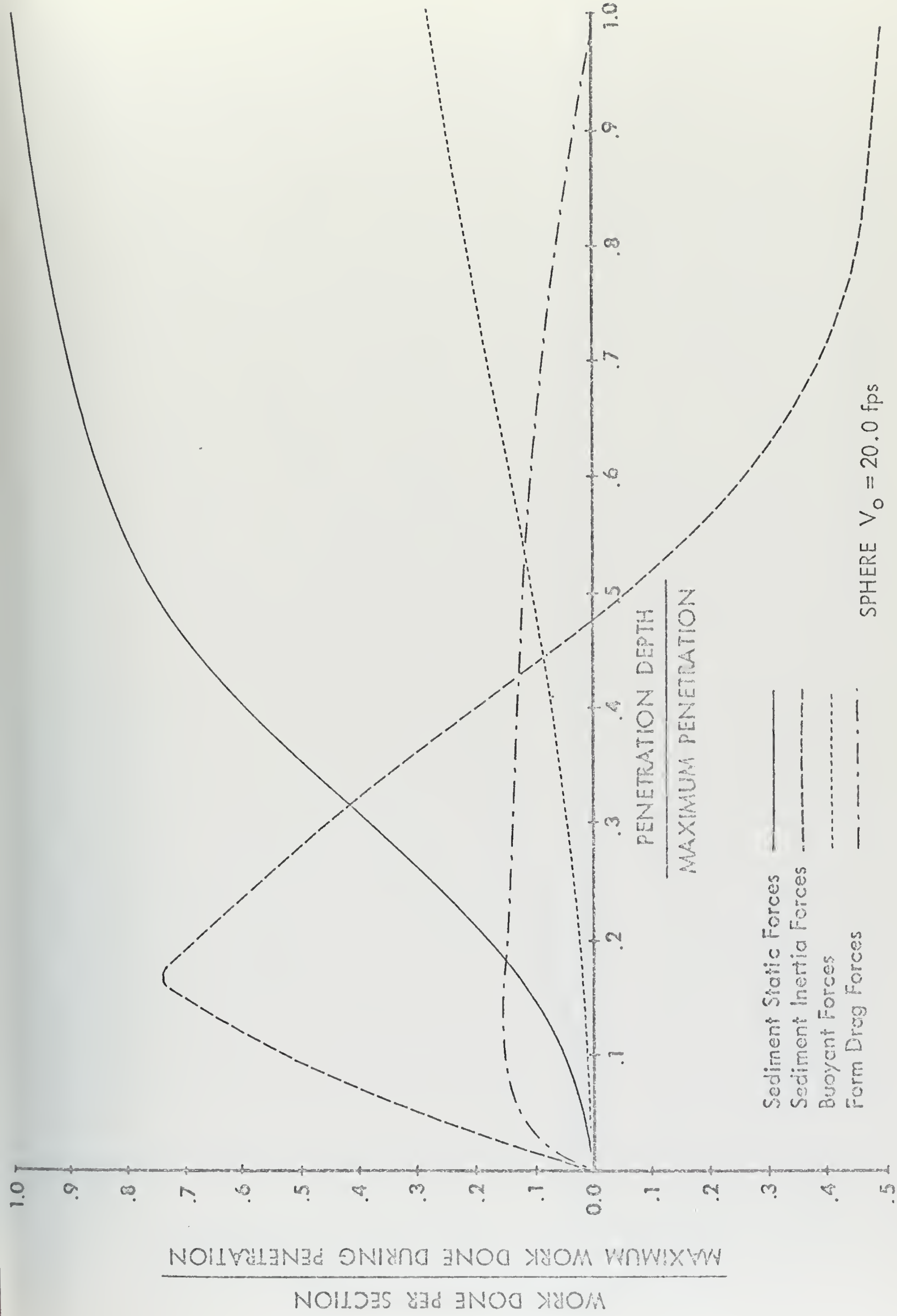
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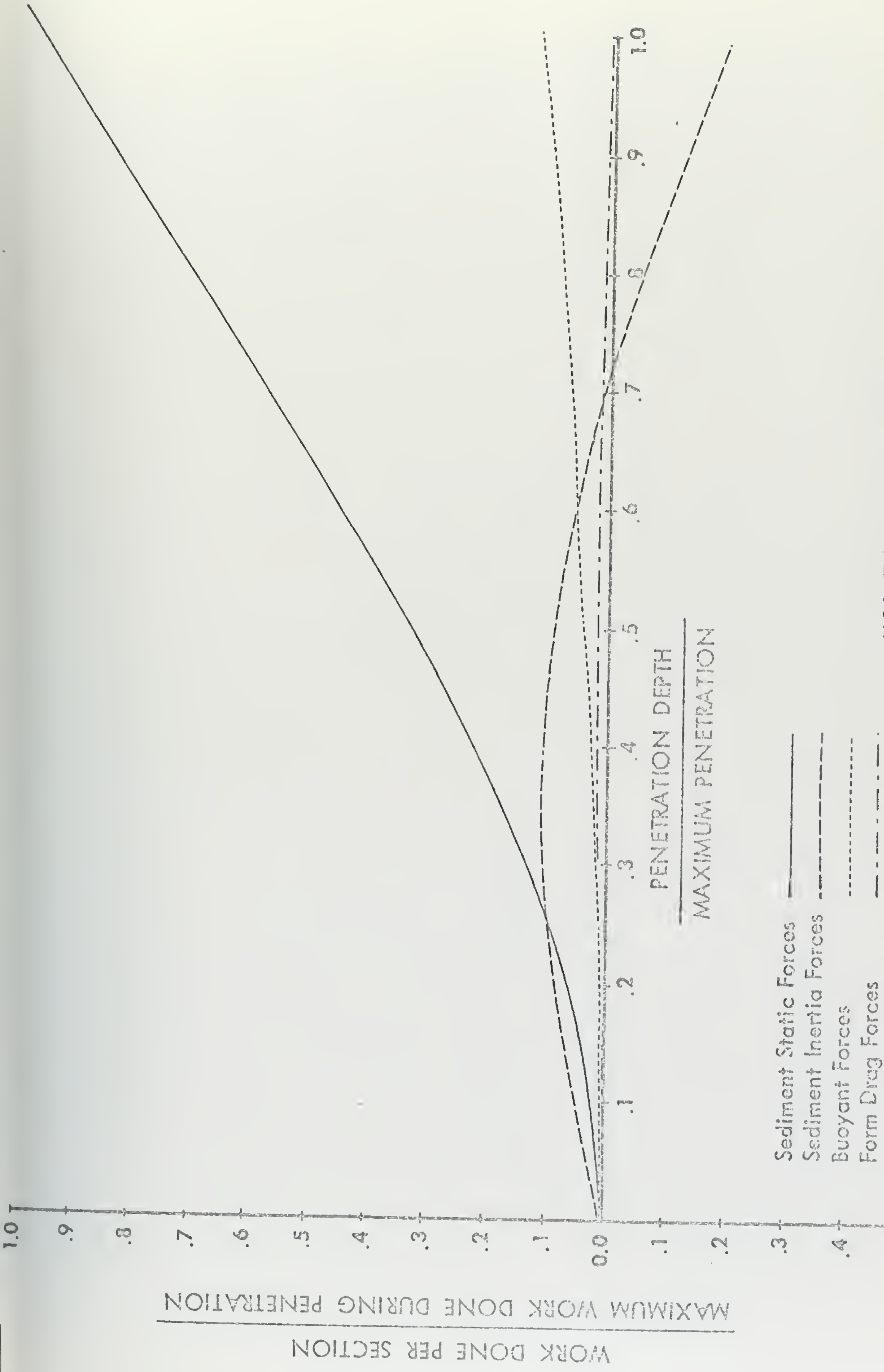
SPHERE V_o = 20.0 fps



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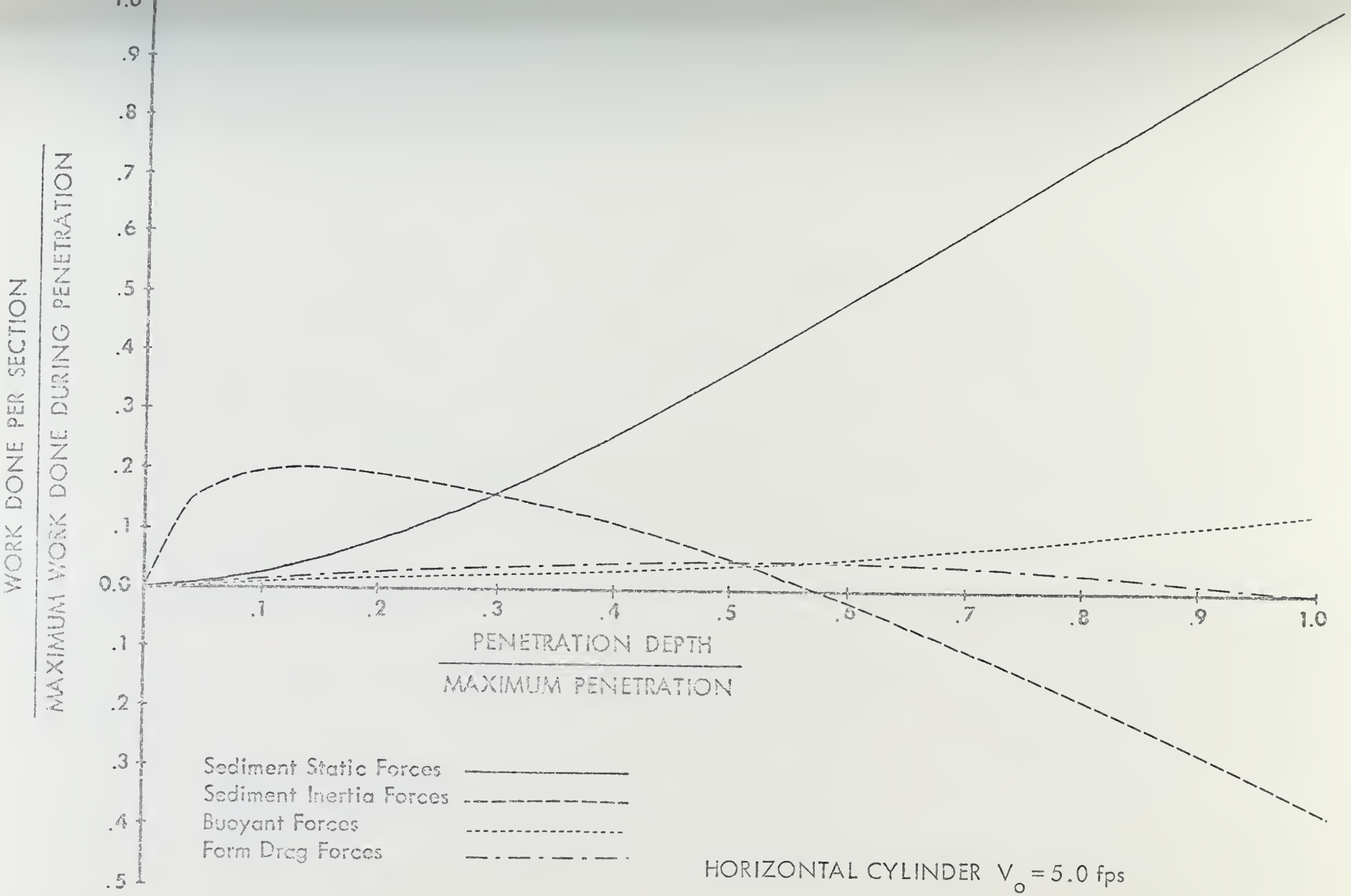

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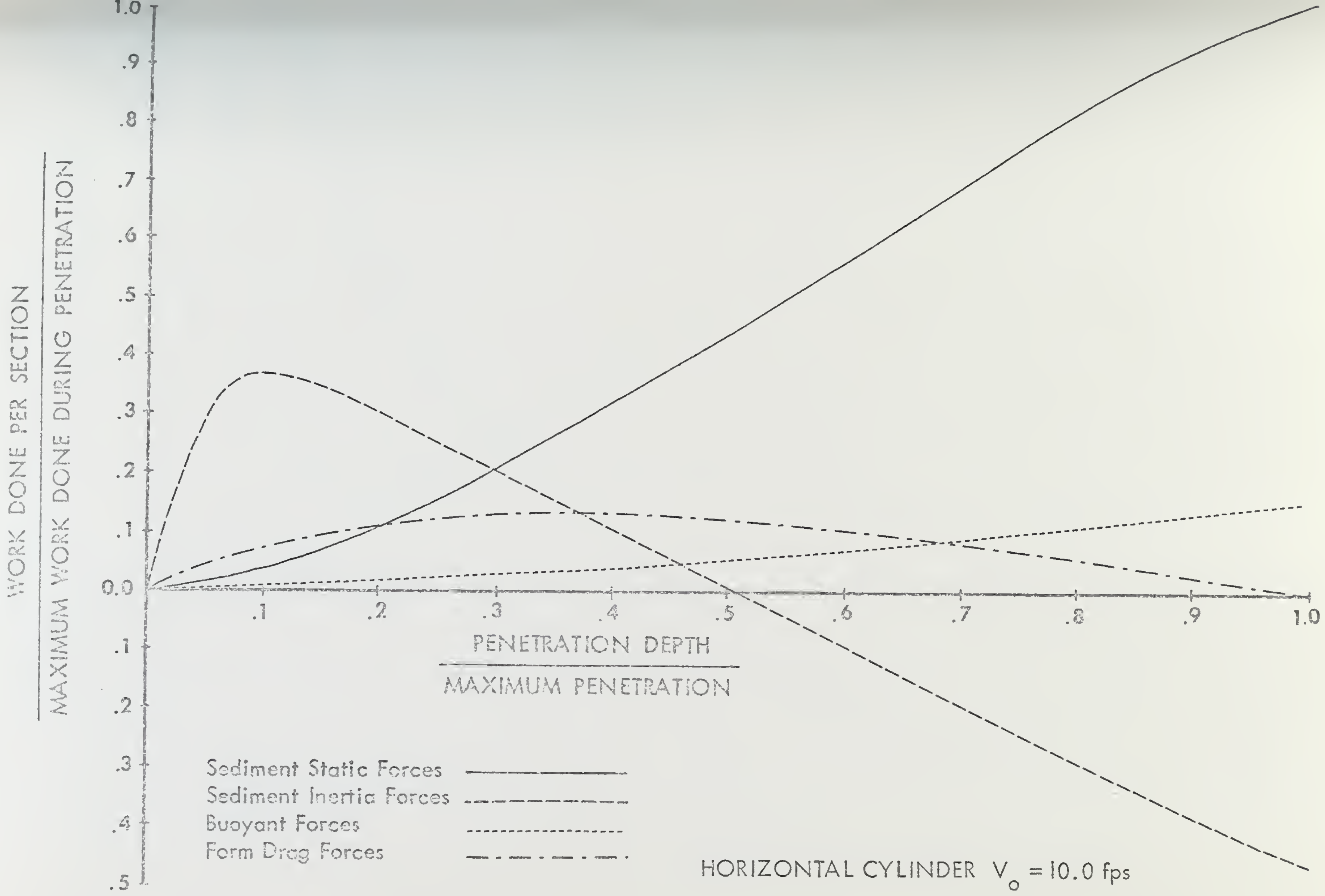

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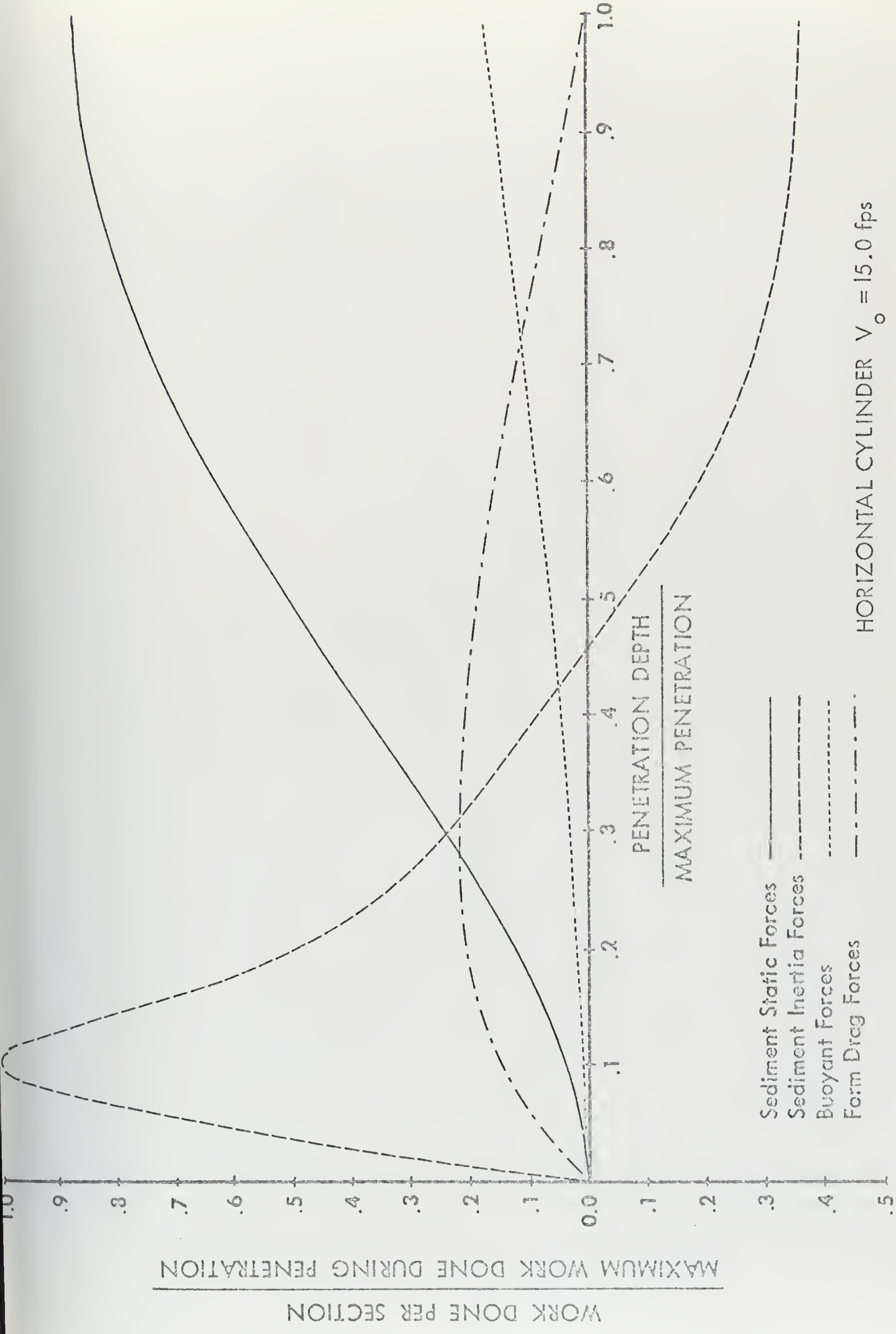
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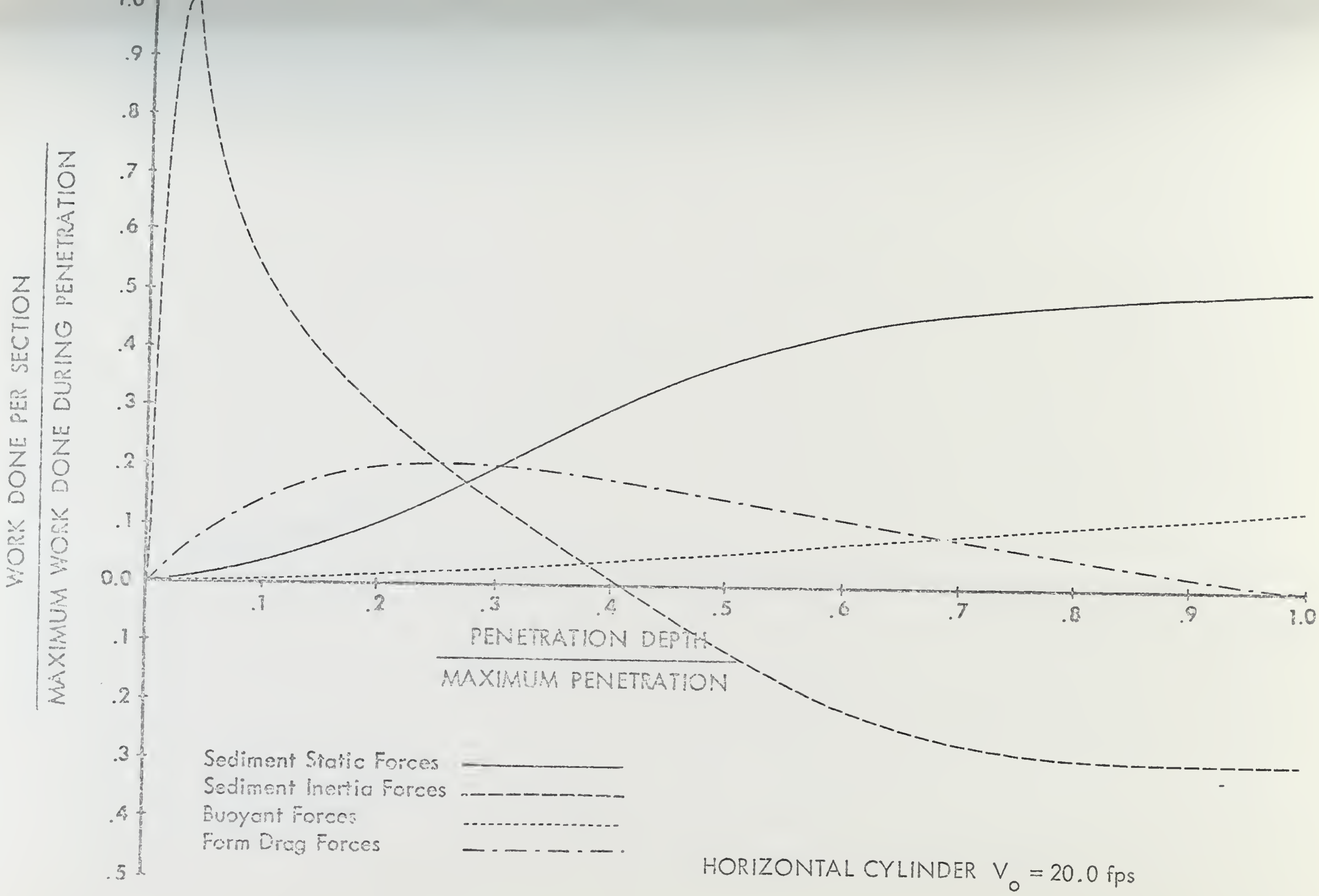WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
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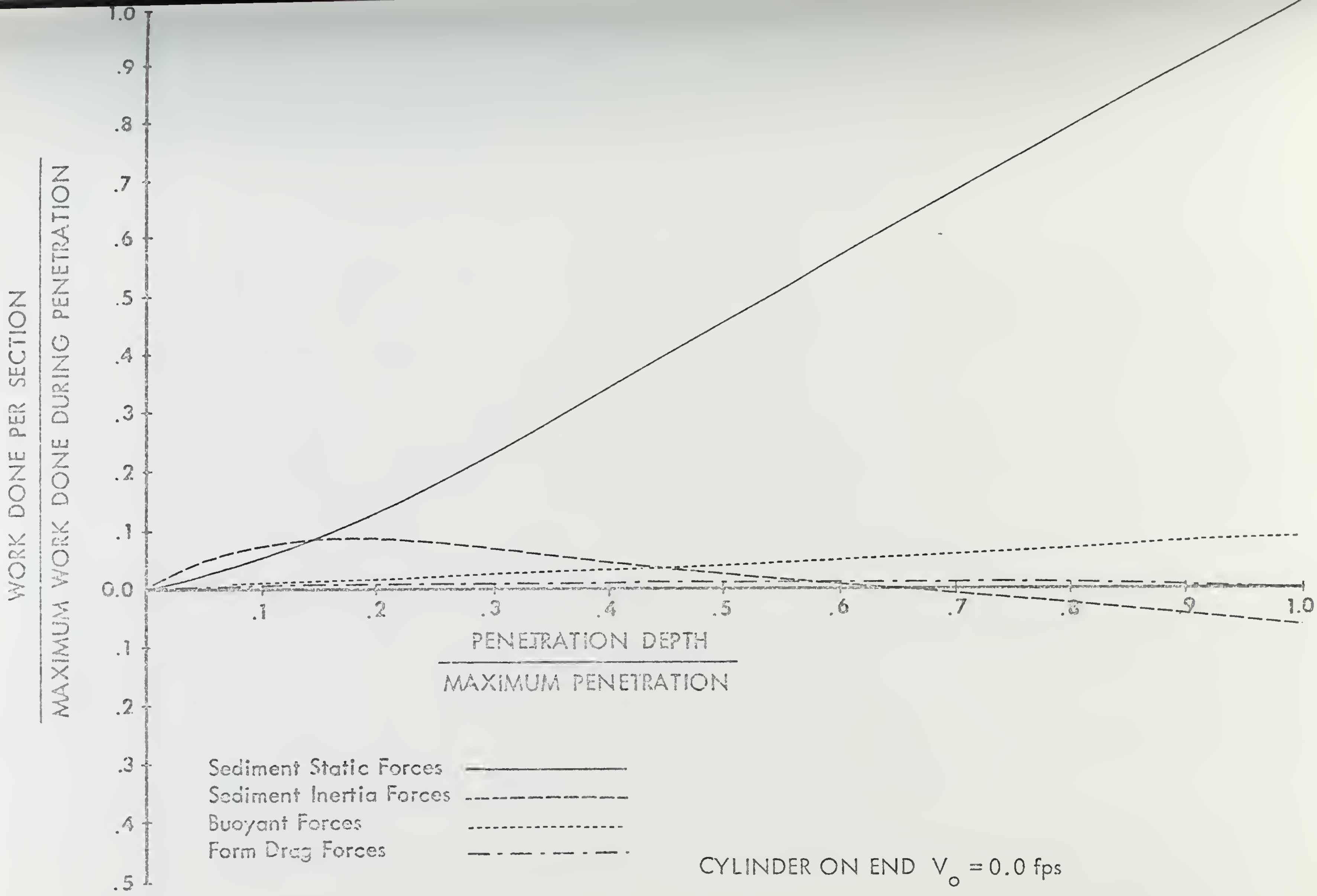

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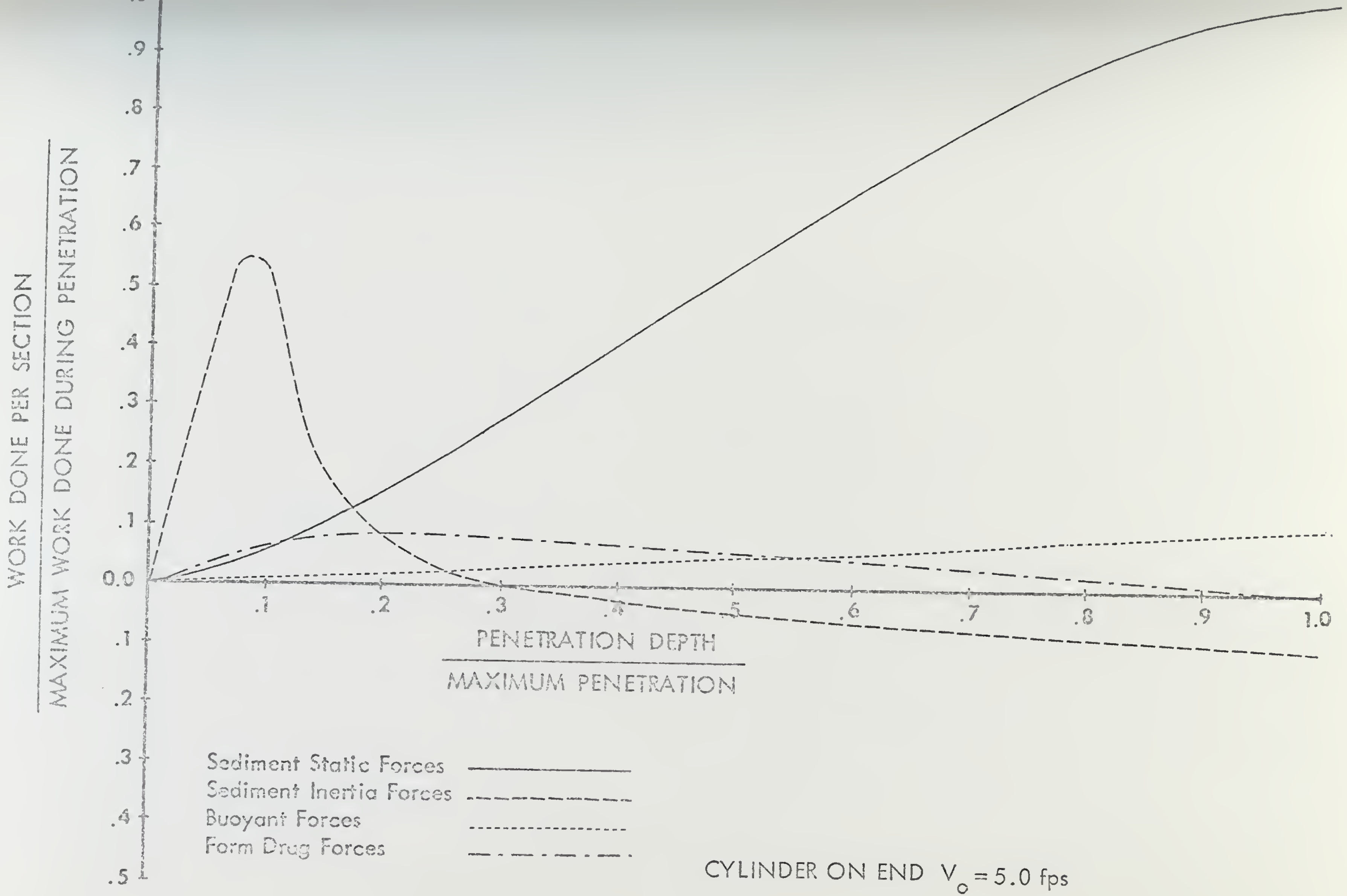

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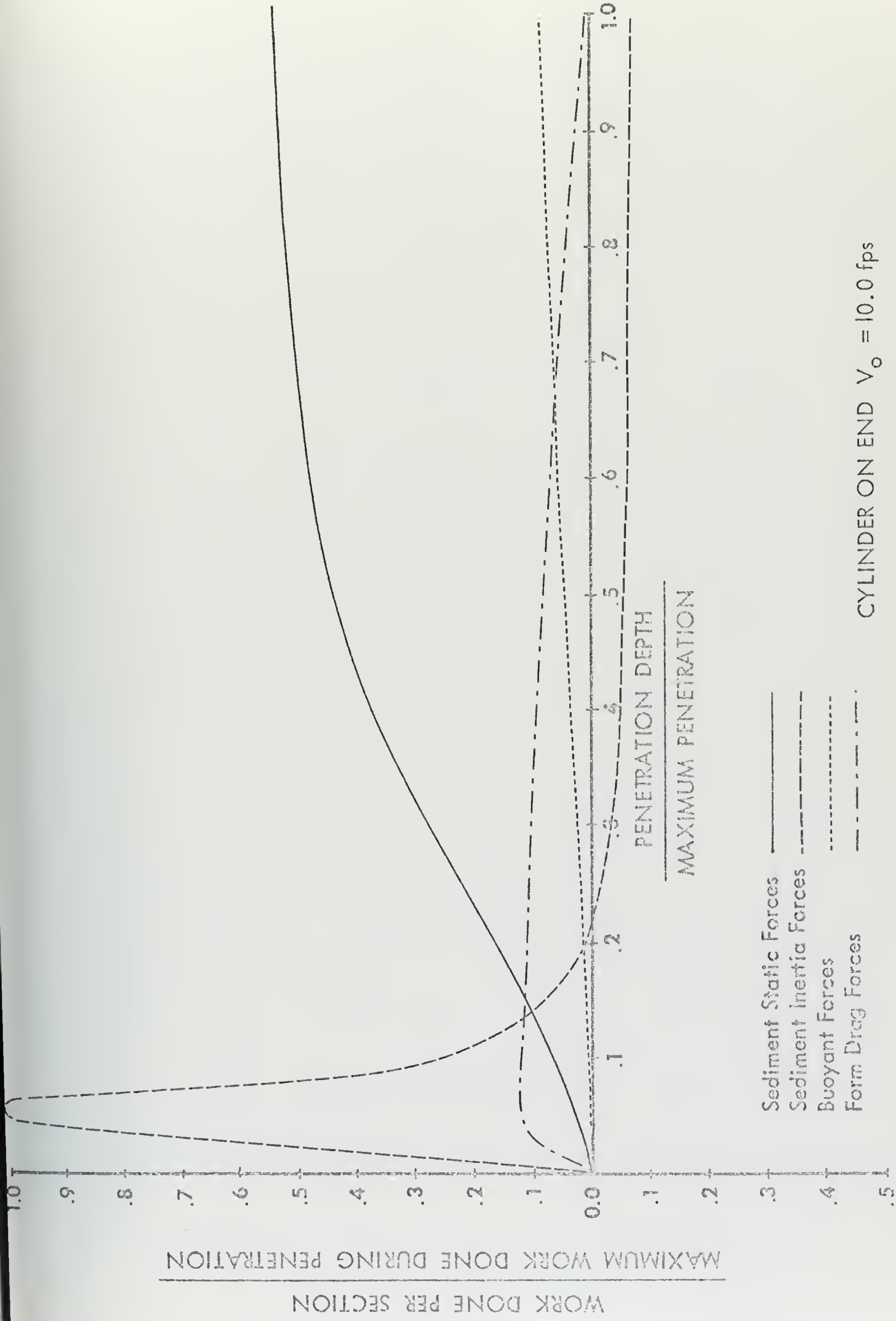
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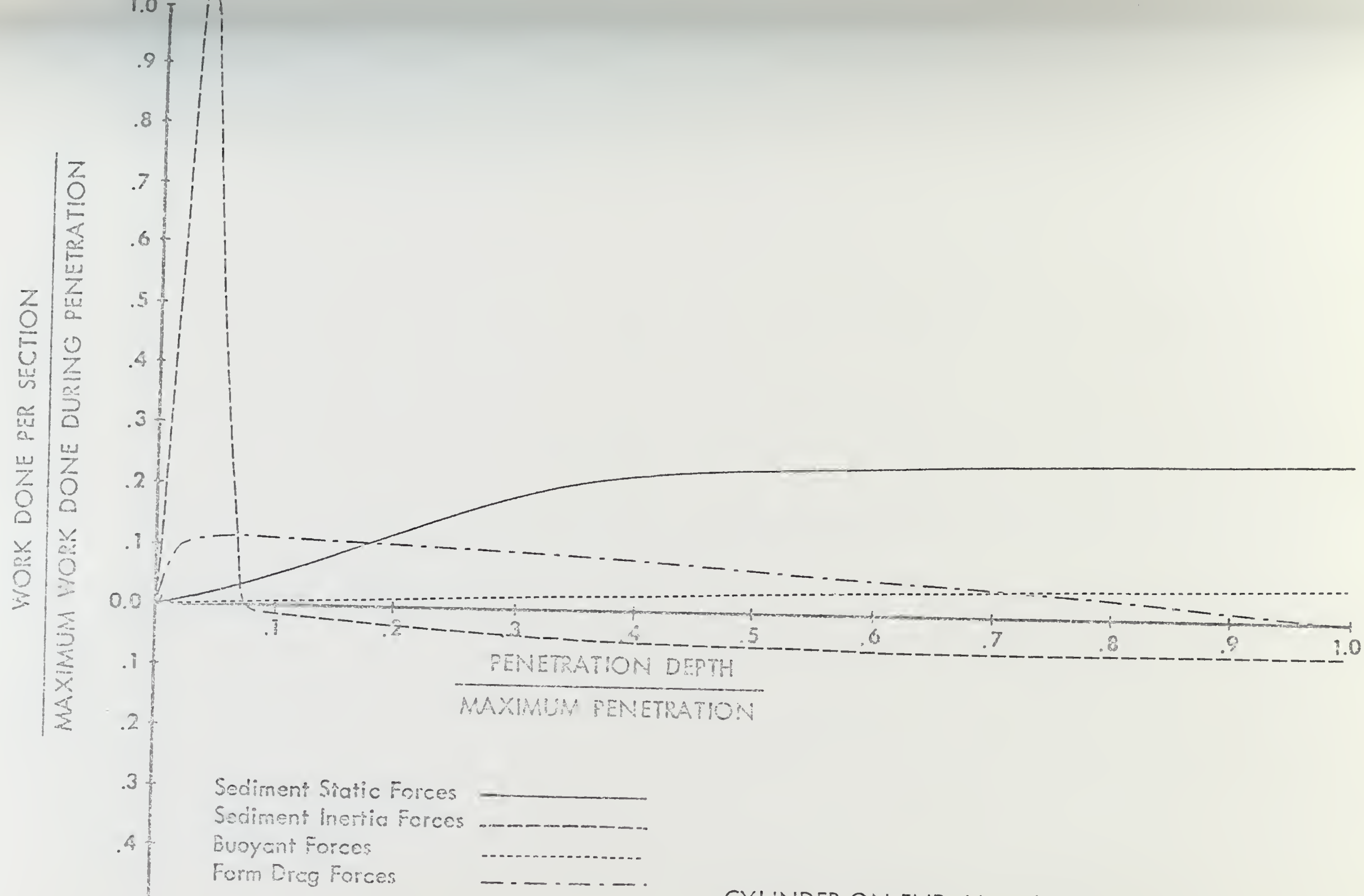

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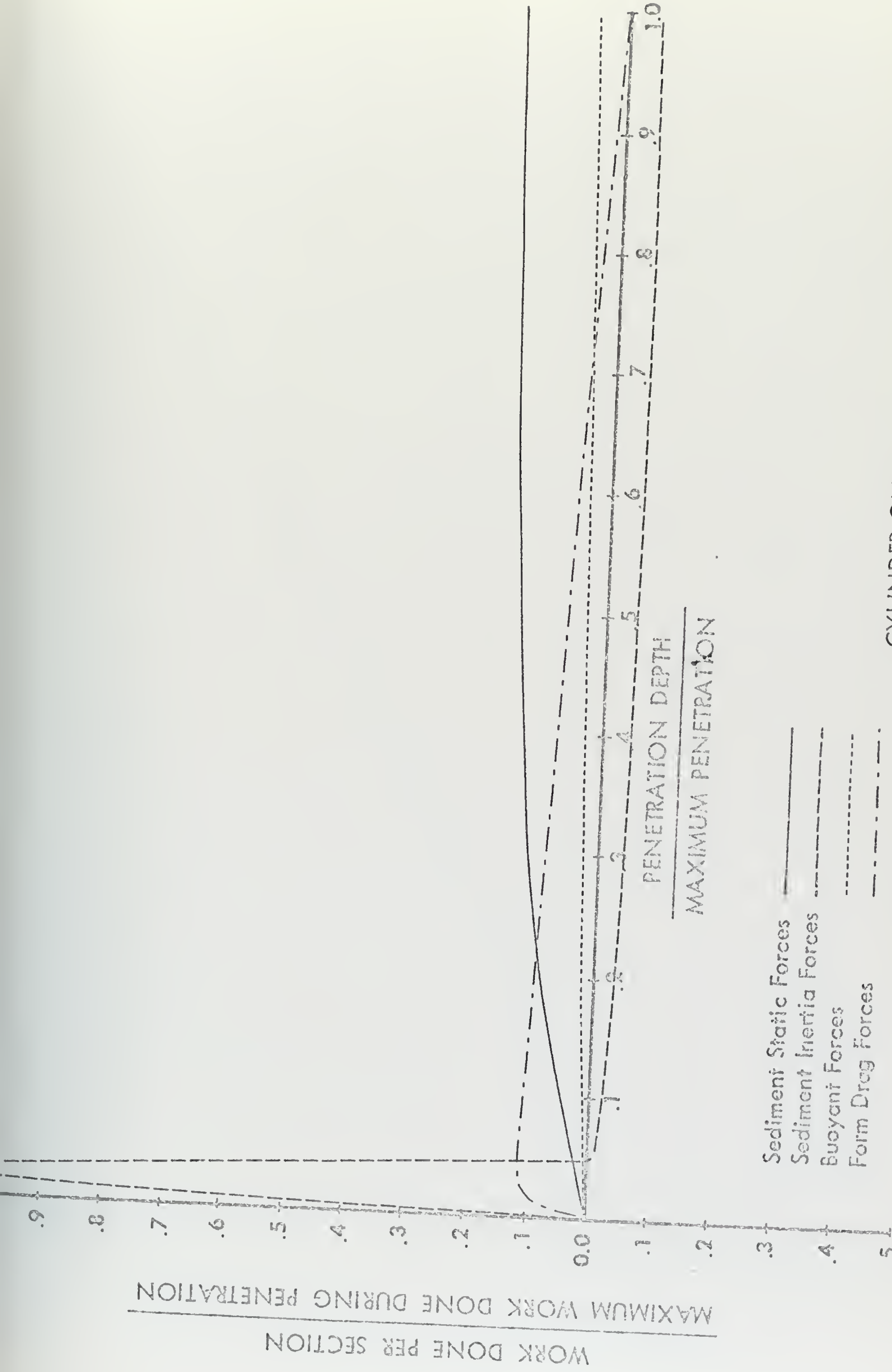

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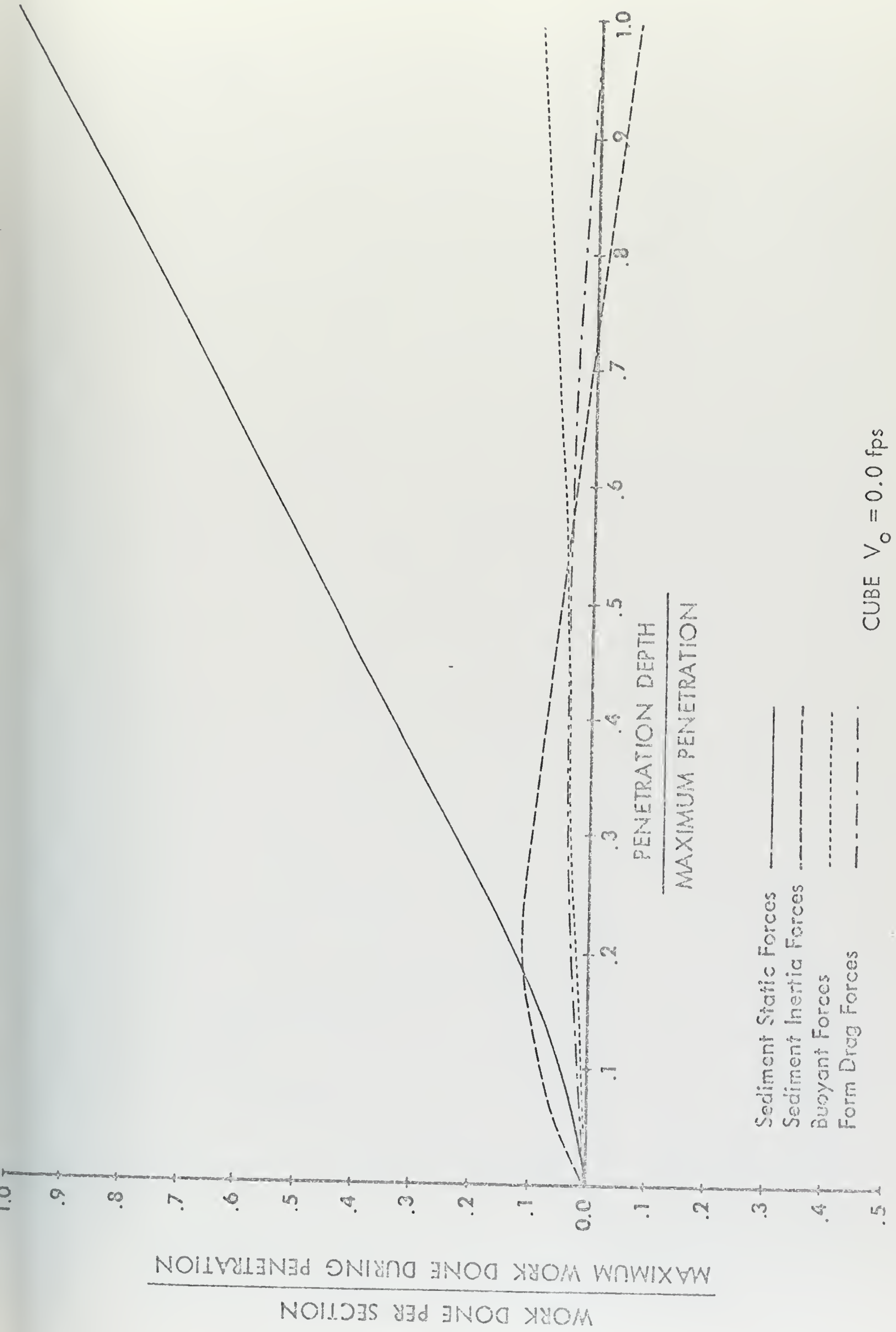
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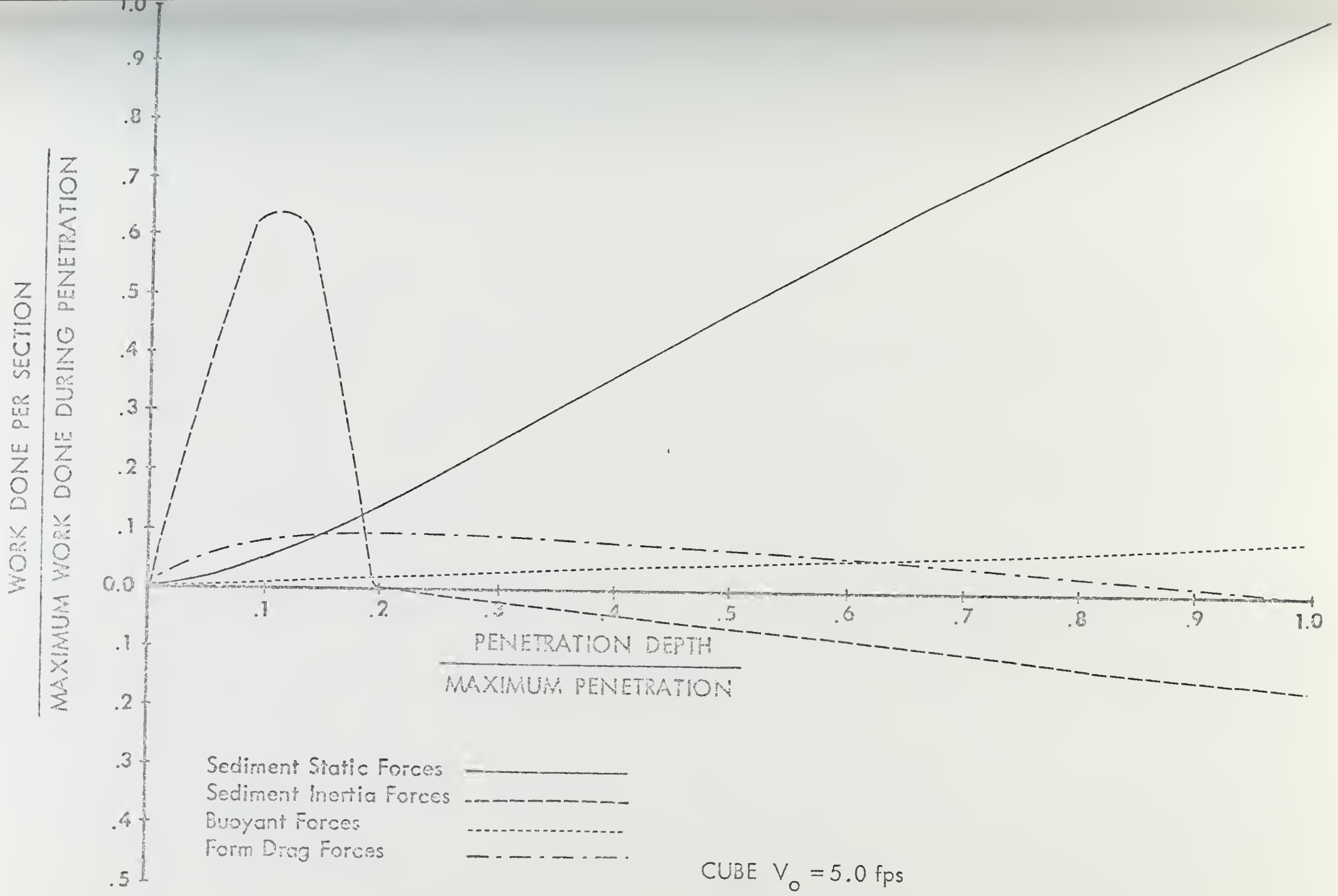
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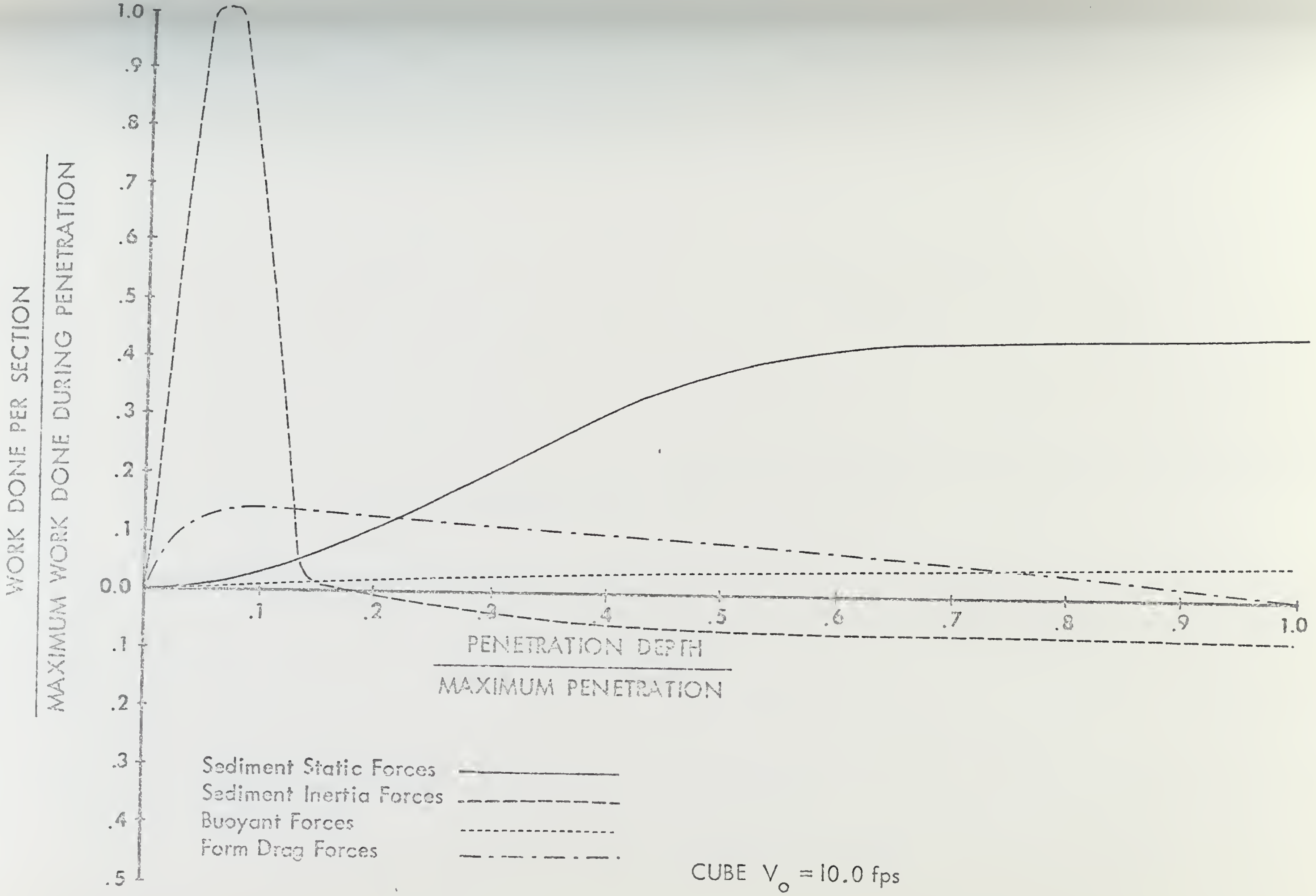
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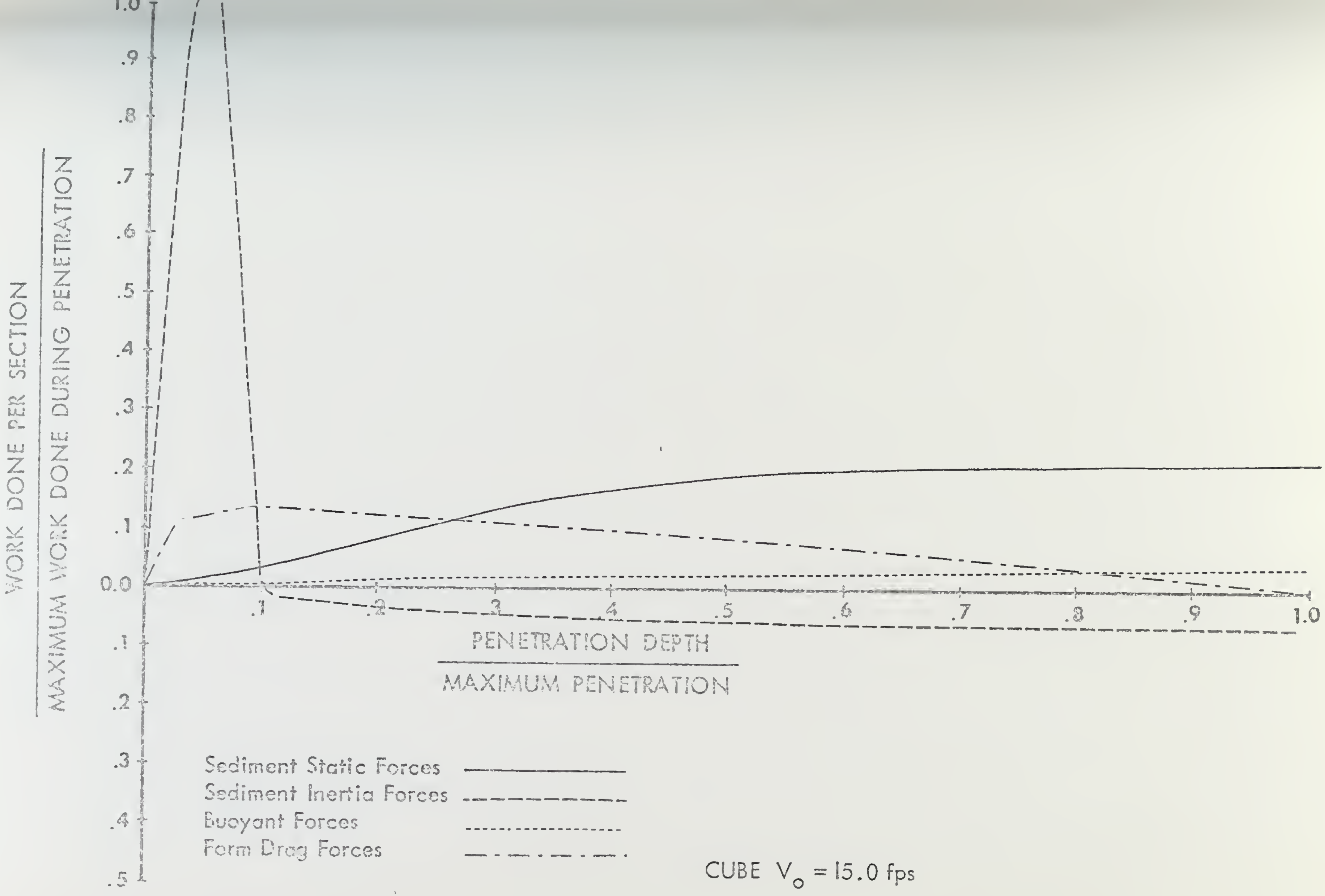
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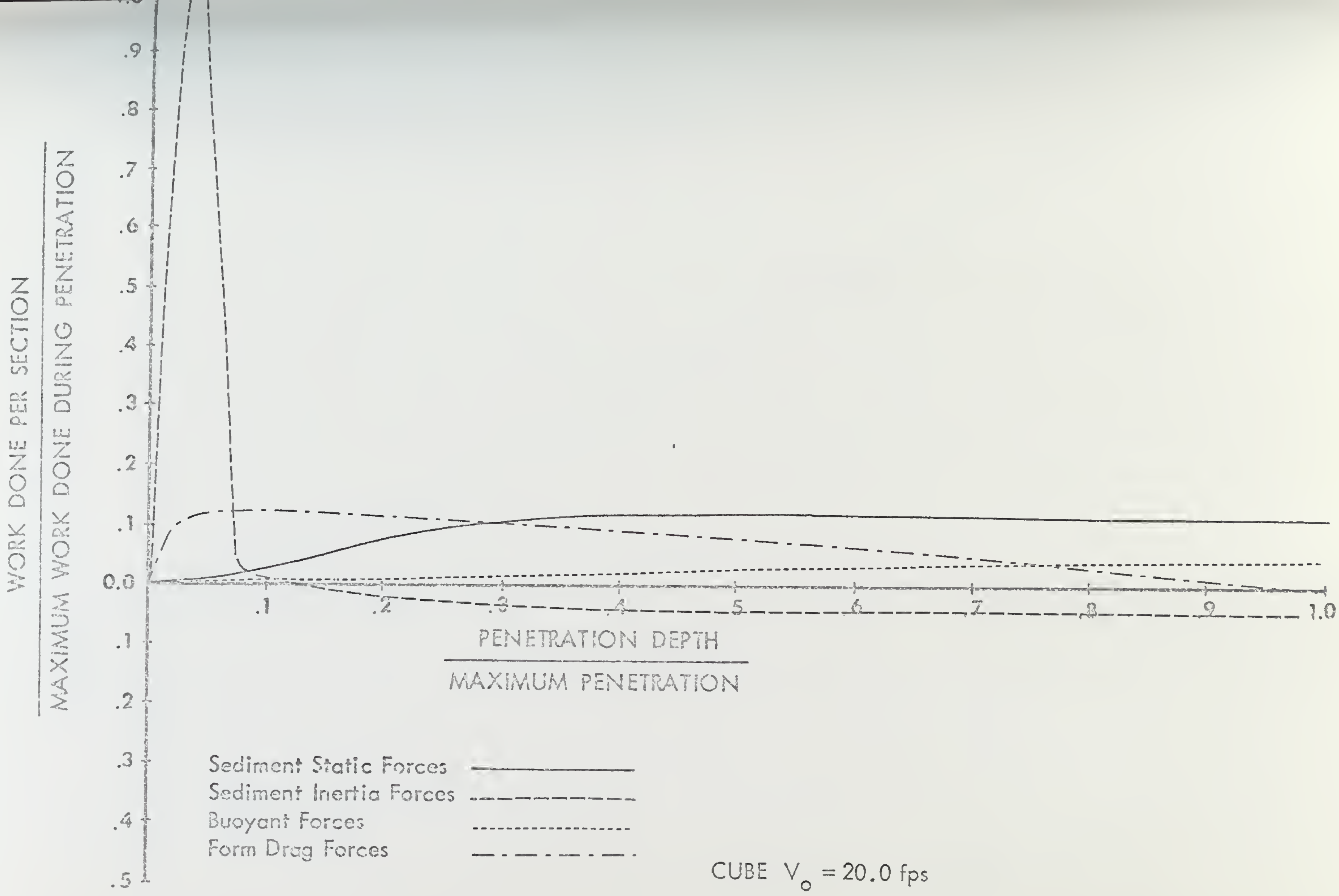WORK DONE PER SECTION
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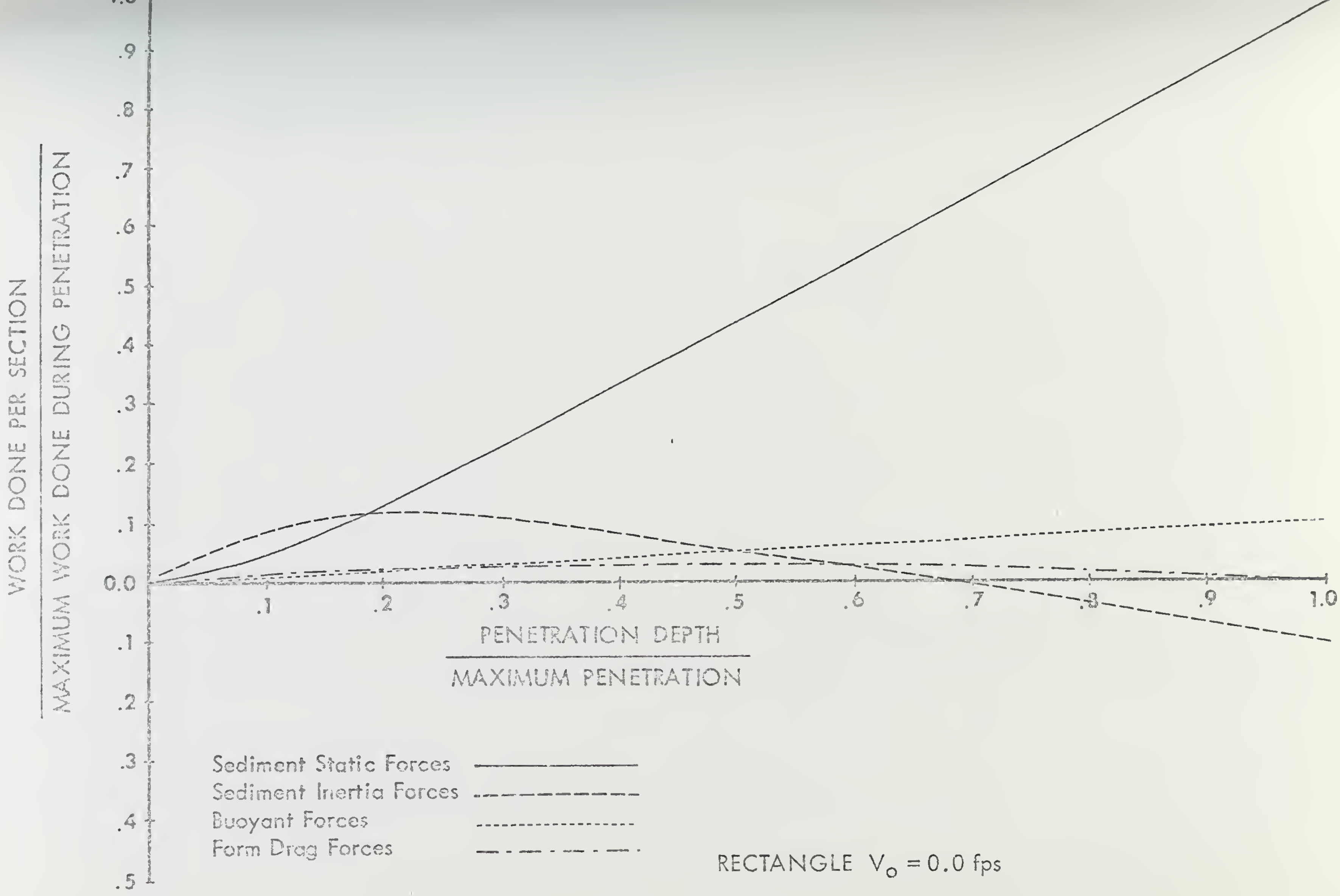
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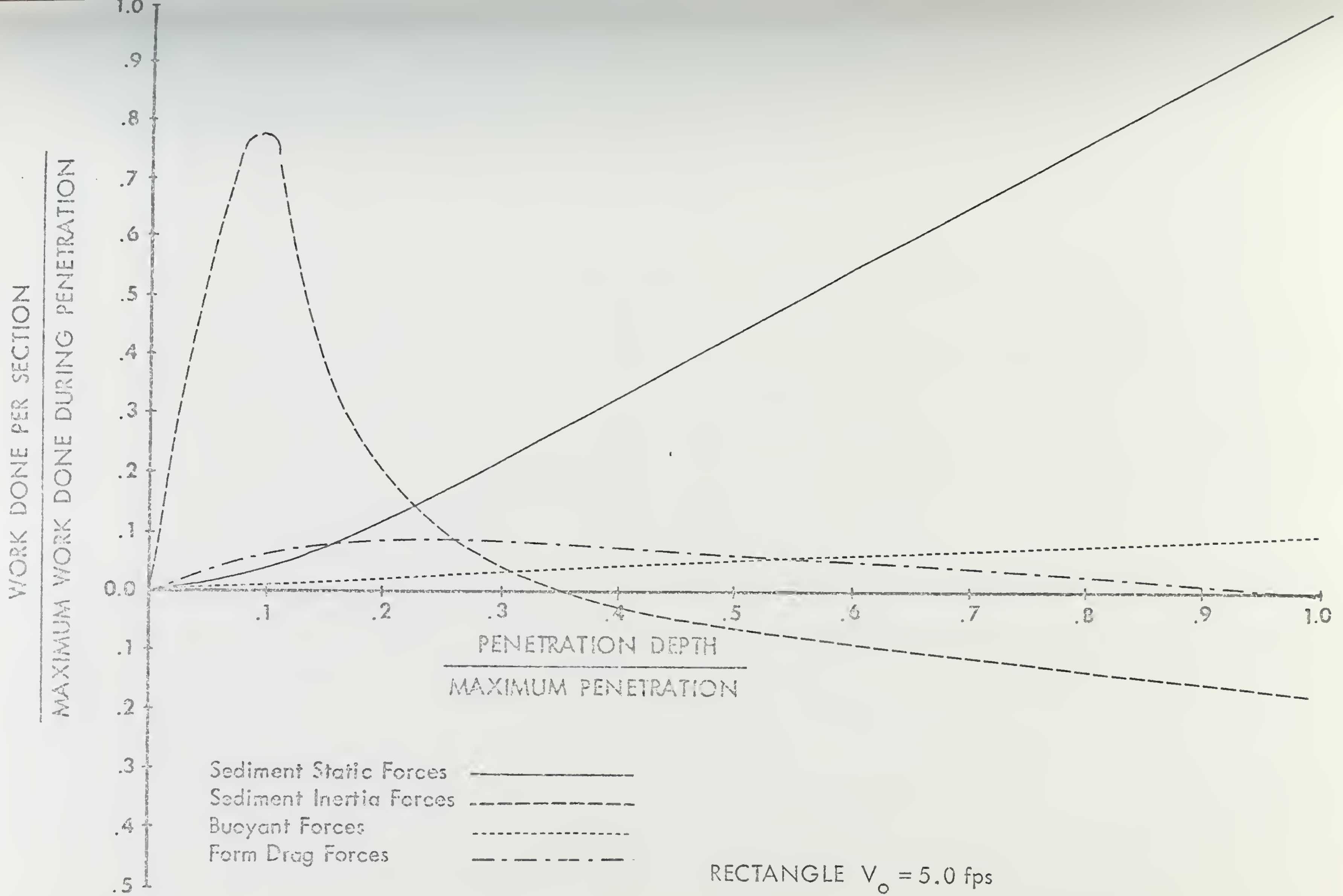
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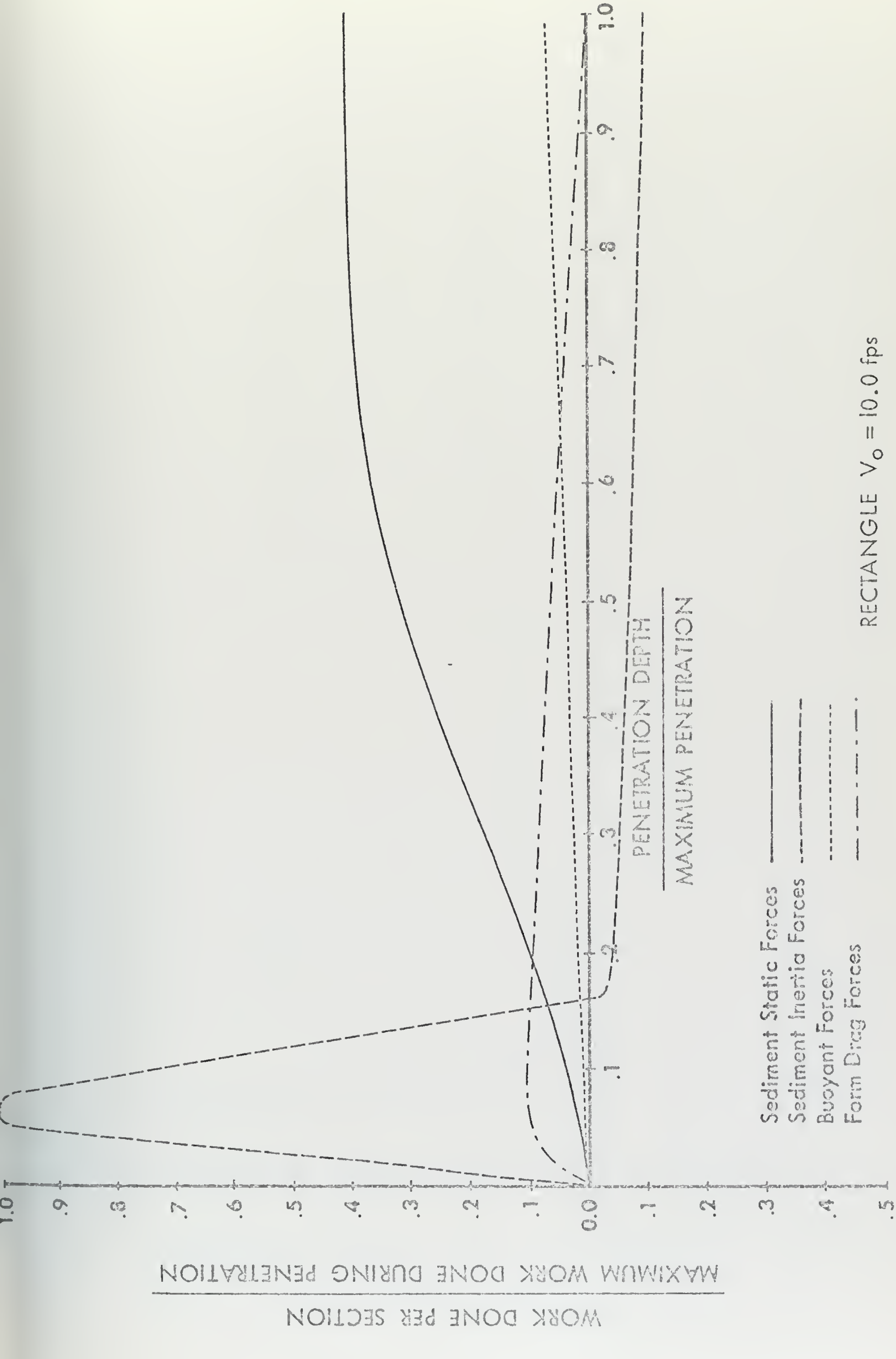
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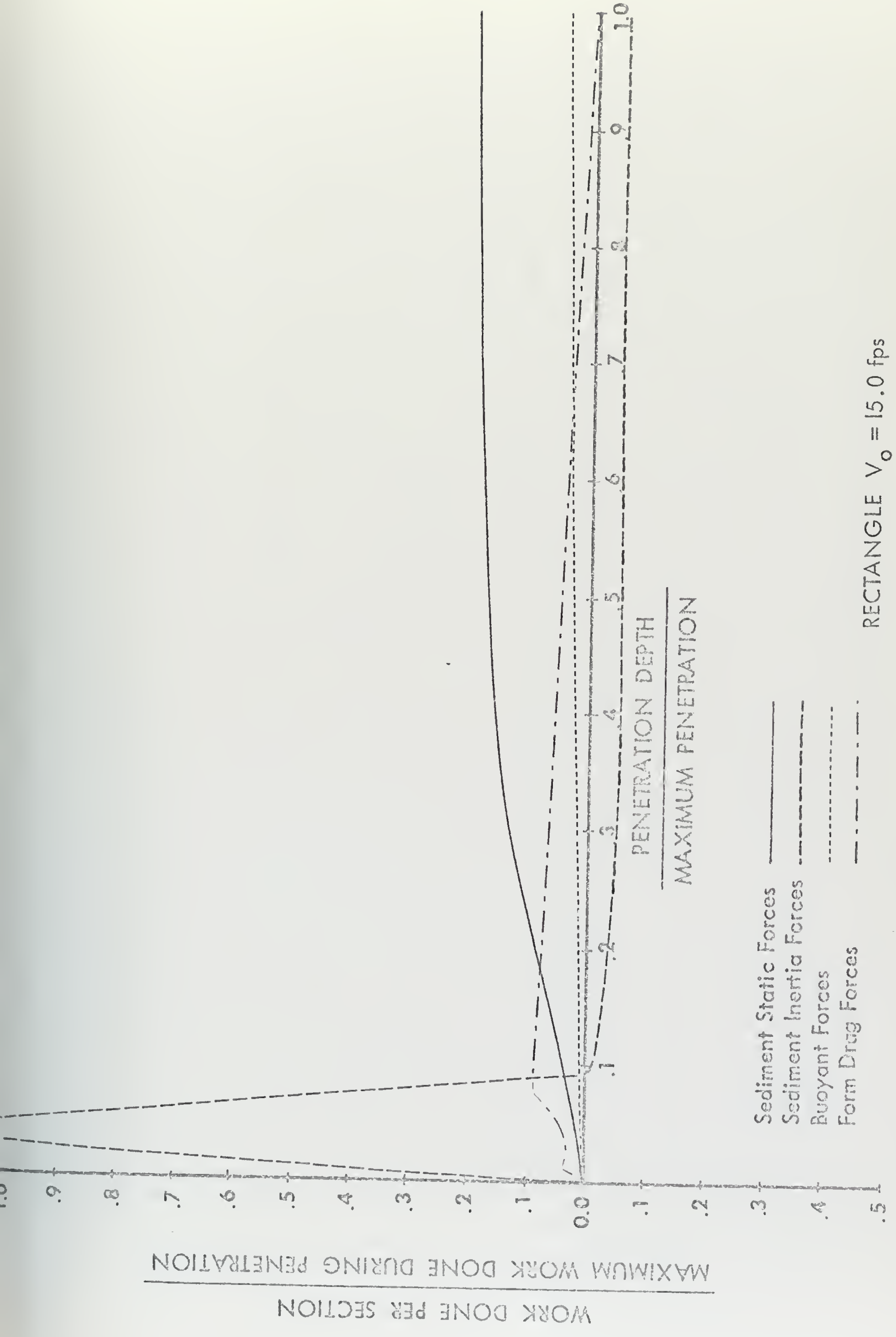
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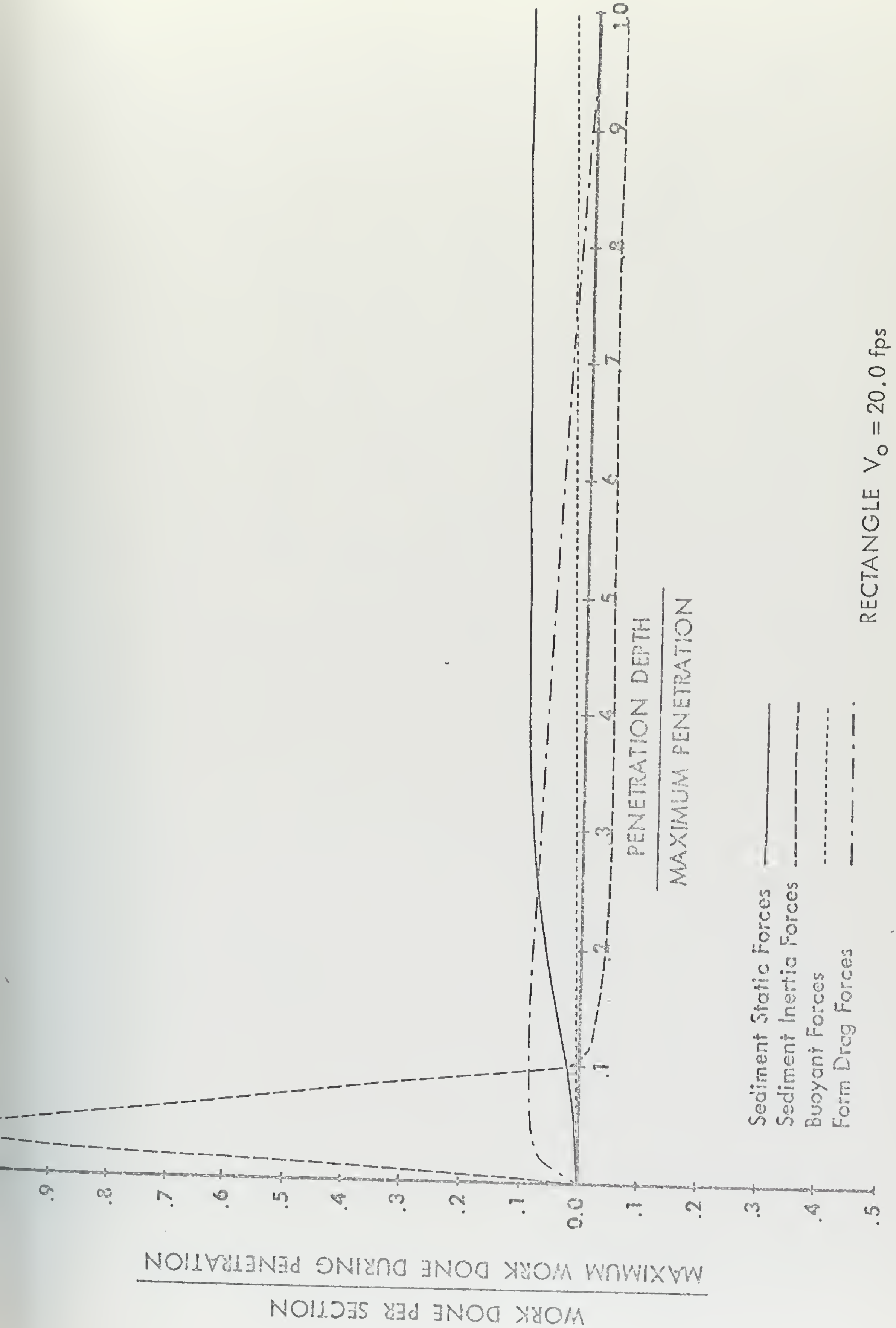WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
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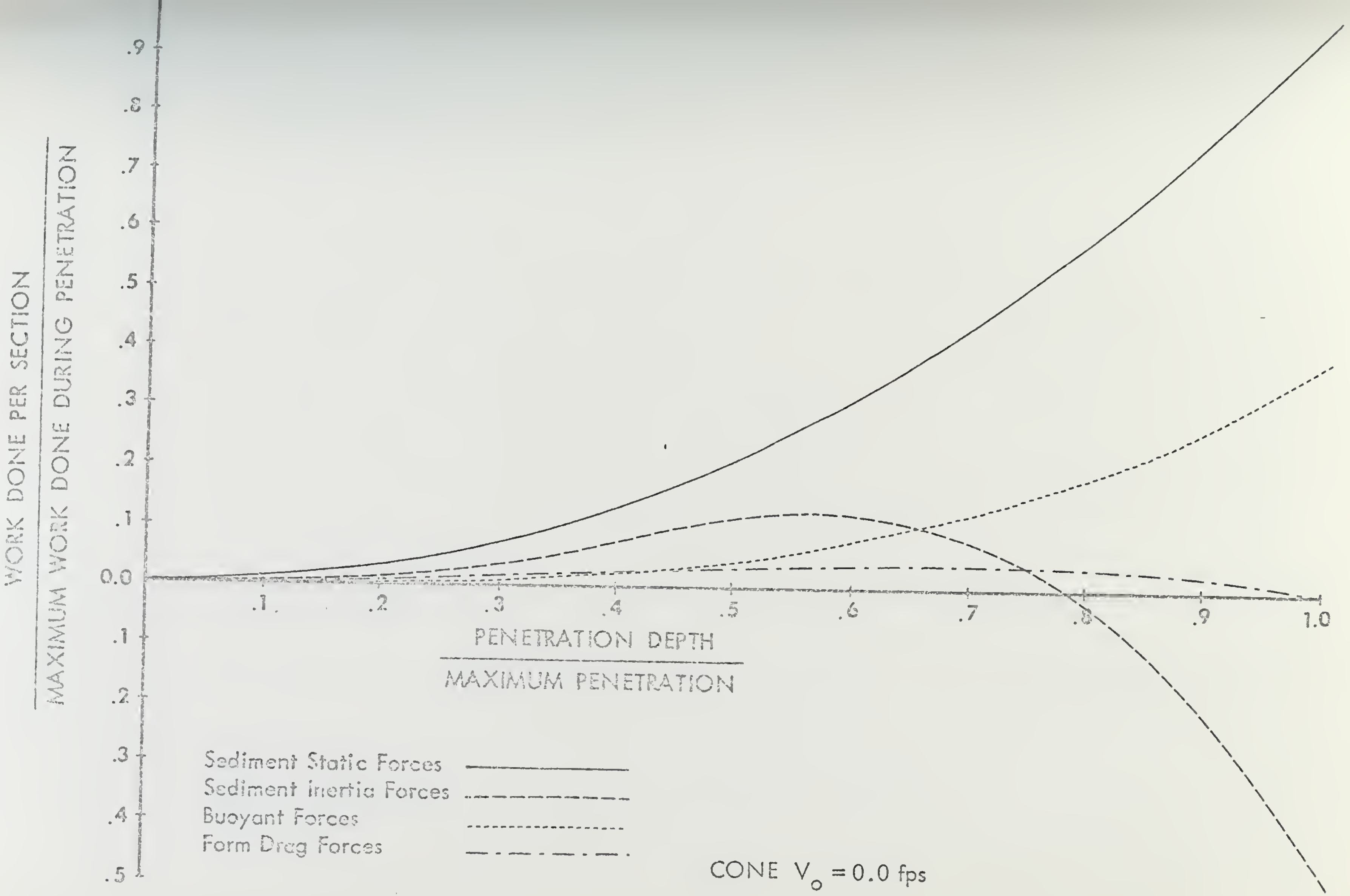
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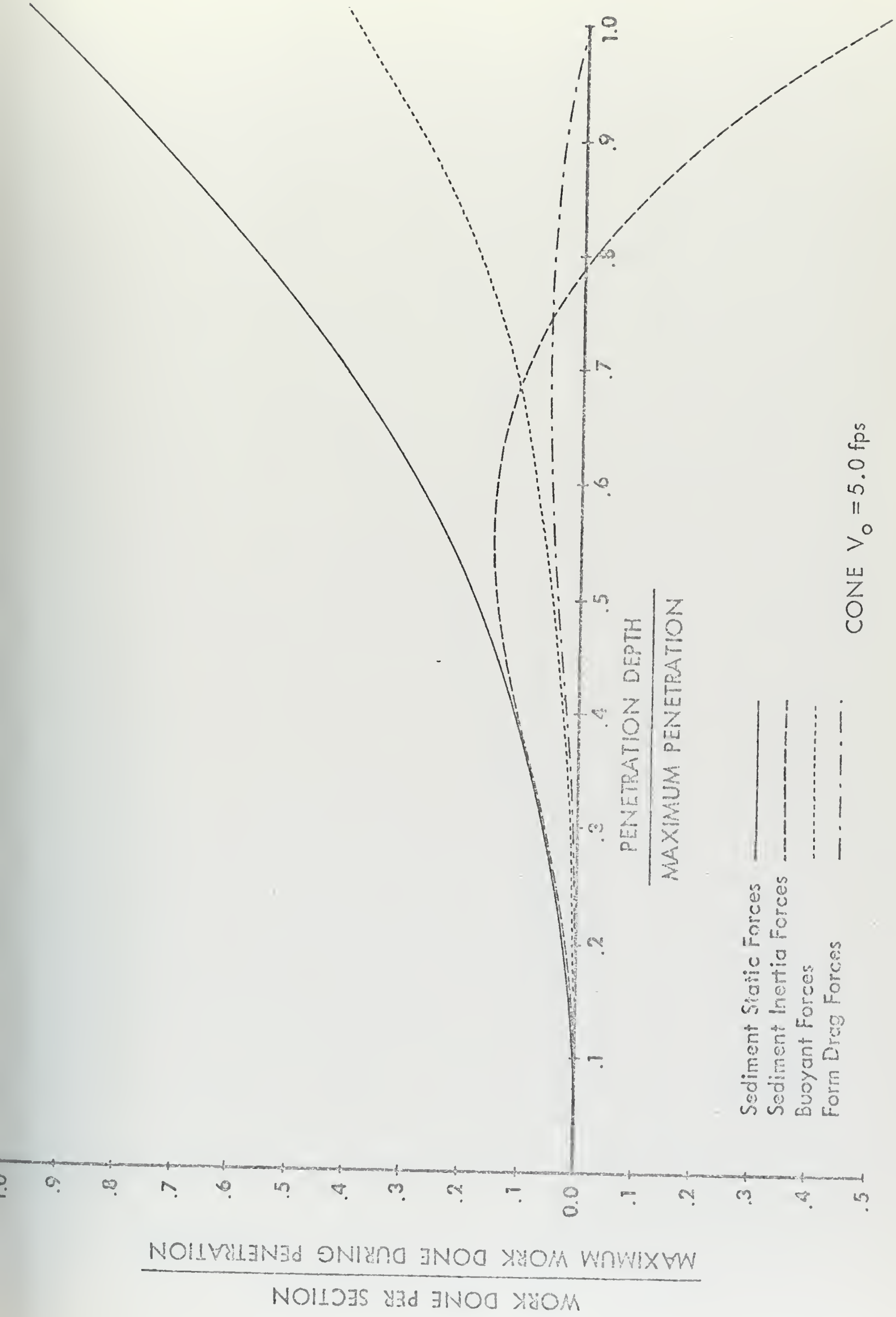
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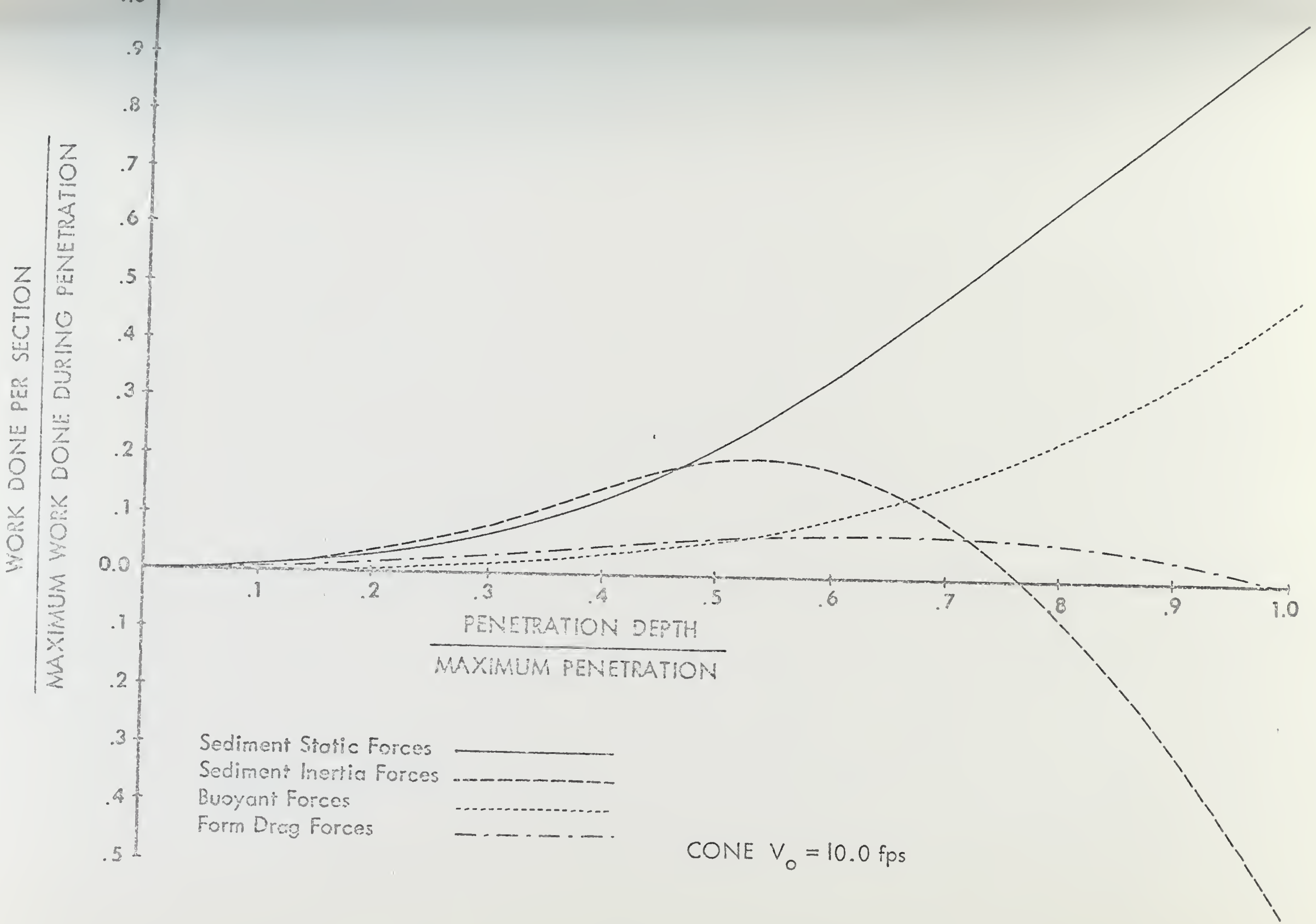
CONE $V_o = 5.0$ fps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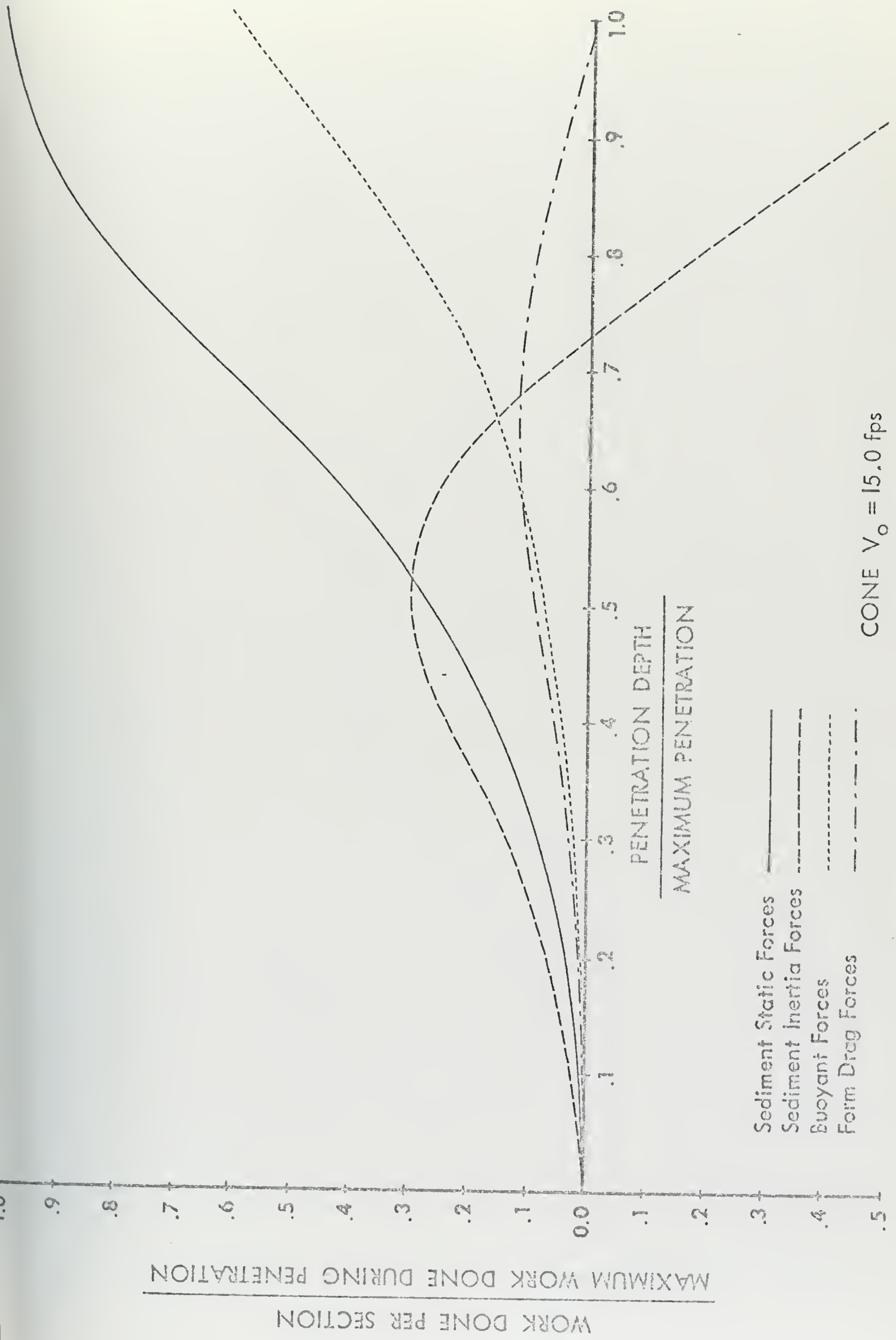
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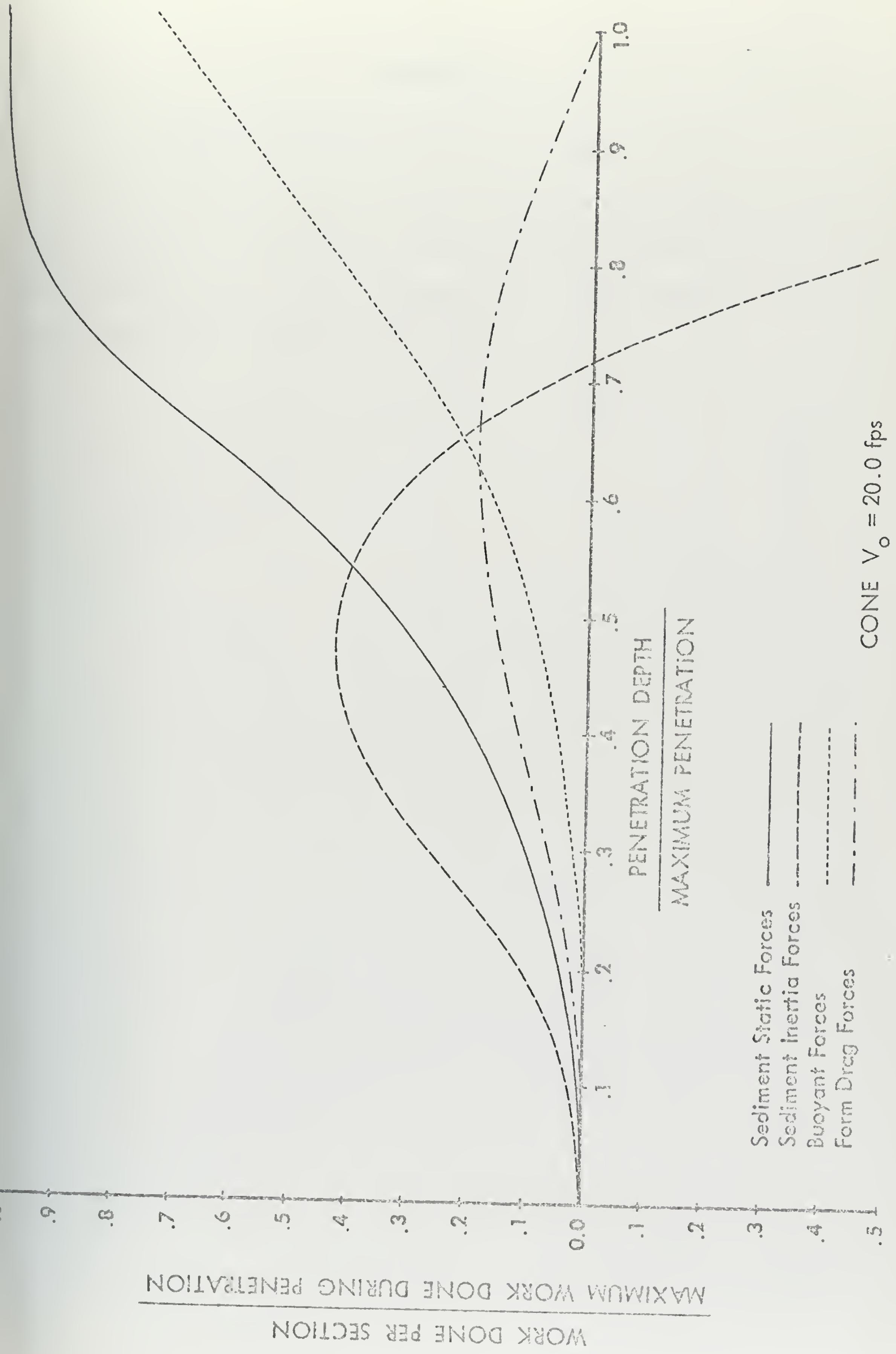
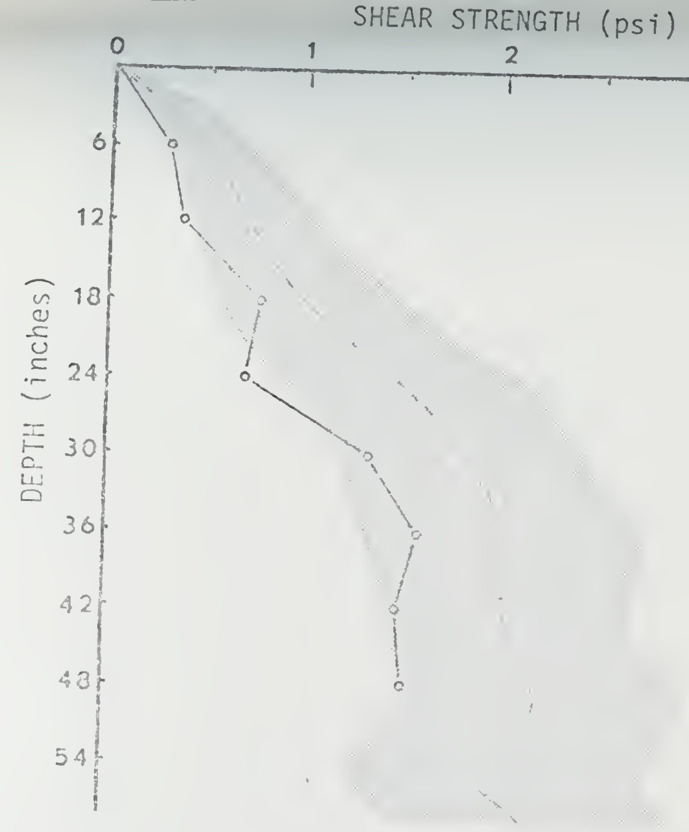
.9
PENETRATION DEPTH
MAXIMUM PENETRATION
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CONE V_o = 15.0 fps


WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
0.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
.1
.2
.3
.4
.5
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
PENETRATION DEPTH
MAXIMUM PENETRATION
Sedimont Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CONE $V_o = 20.0$ fps

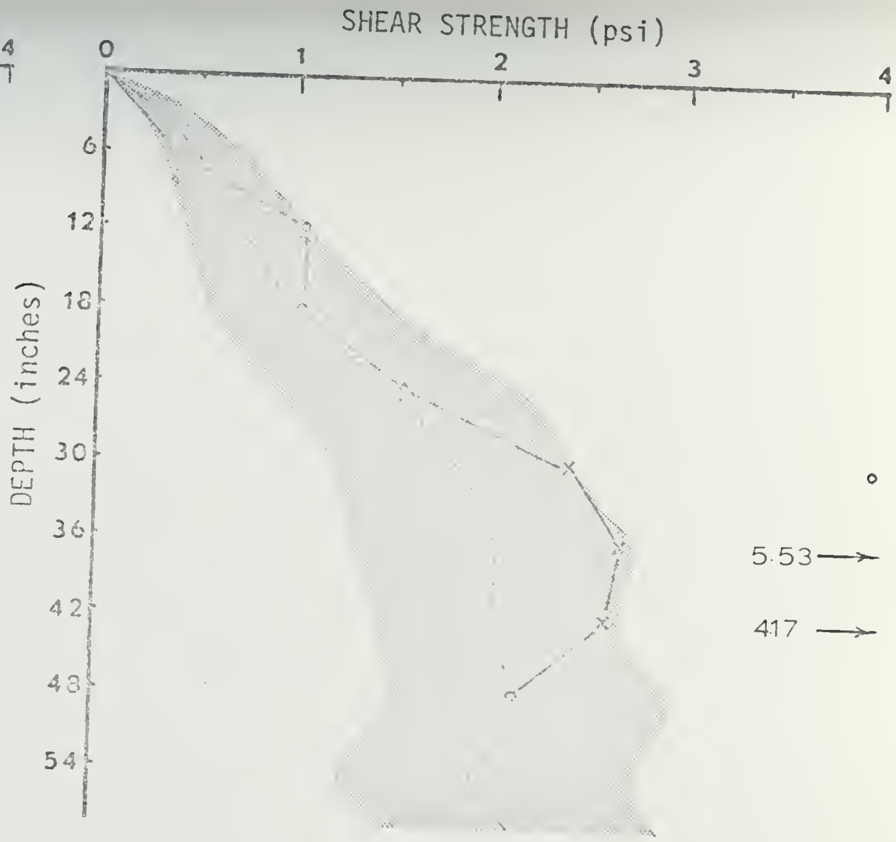
APPENDIX B

SHEAR STRENGTH PROFILES OF THE TEST PIT

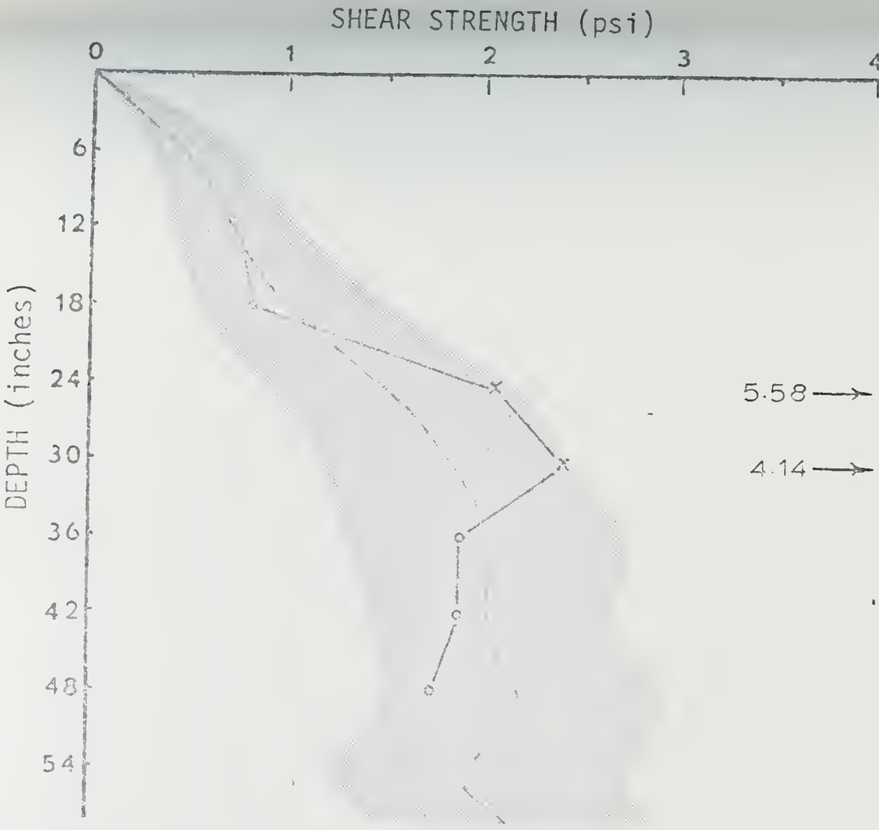
The shear strength profiles at each drop station are illustrated together with the adjusted profile used in the penetration prediction computation. The profiles are in the same order as listed in Table VII.



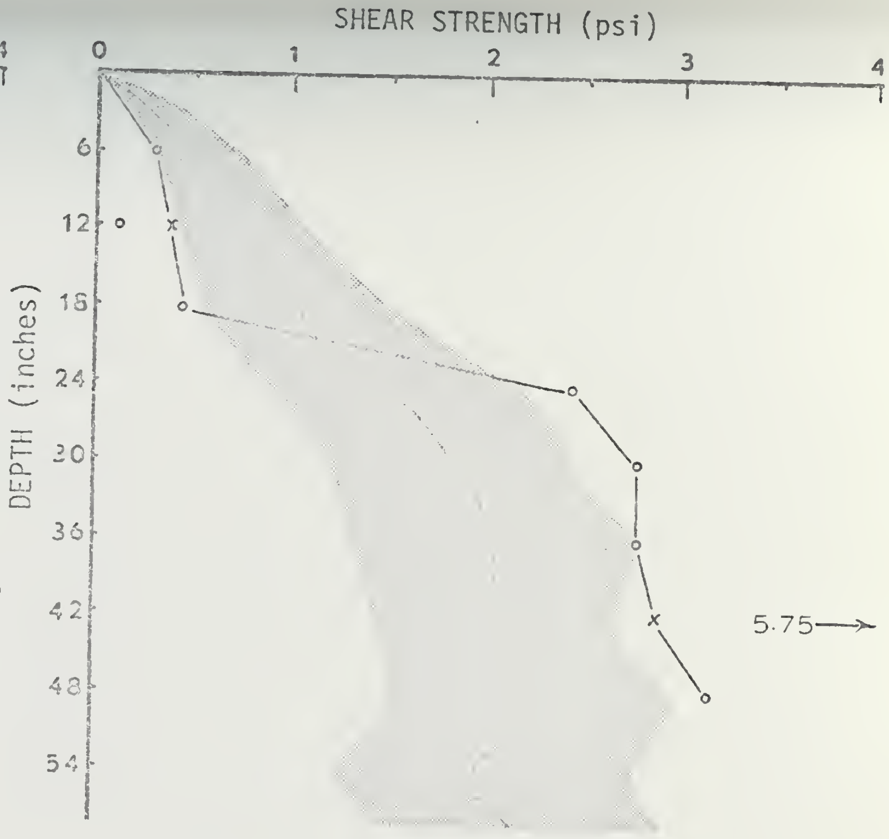
SPHERE
Velocity 0.0 fps
Station 6



SPHERE
Velocity 5.0 fps
Station 7

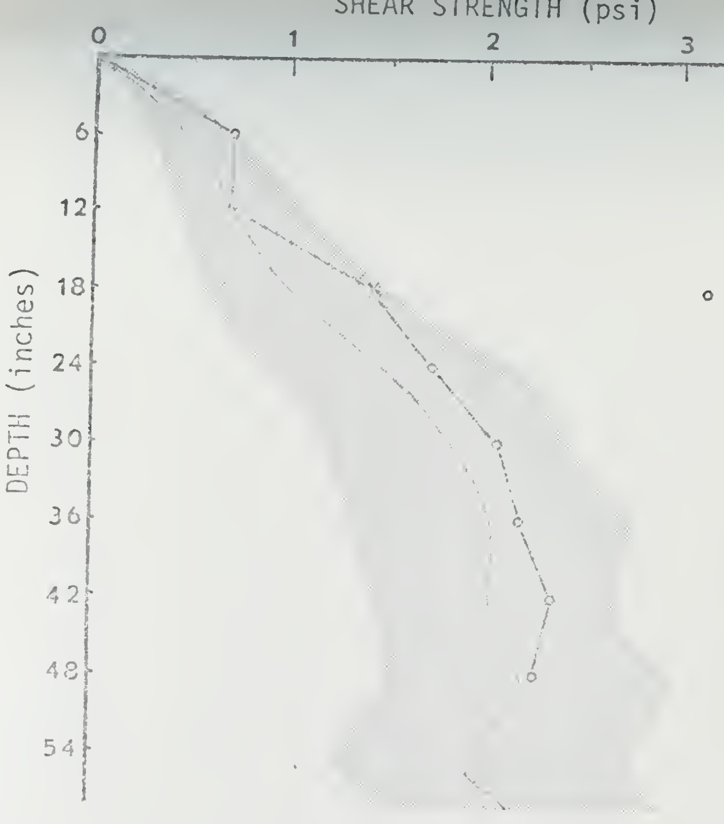


SPHERE
Velocity 10.0 fps
Station 9

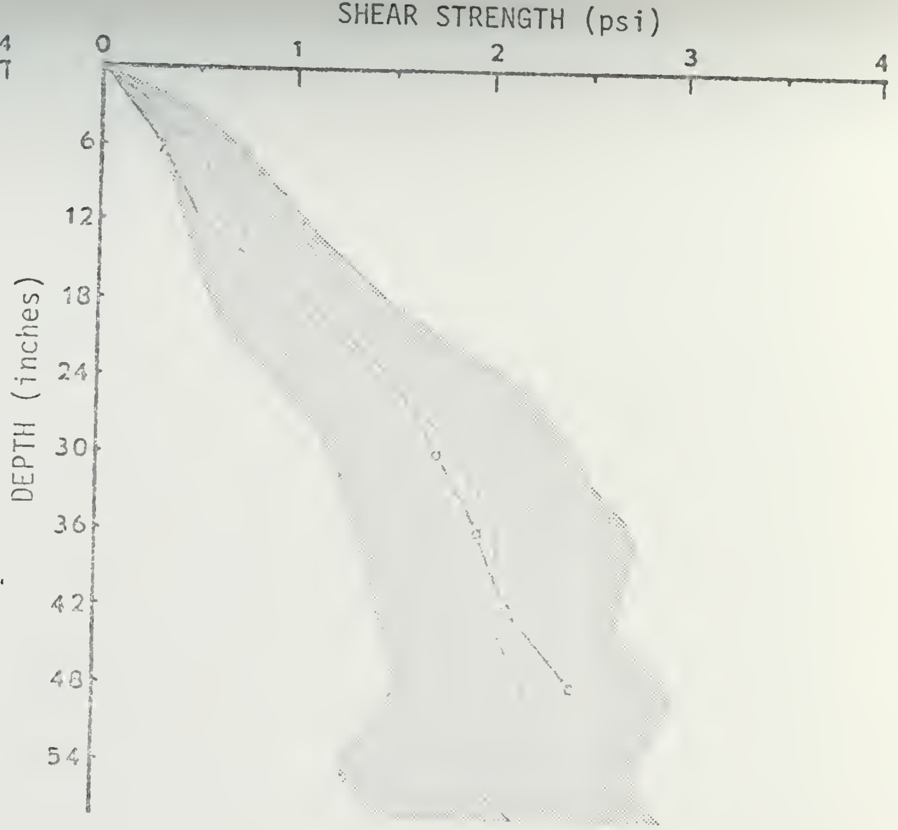


SPHERE
Velocity 15.0 fps
Station 20

○ observed
× adjusted
------ mean
——— shear strength used
▨ one standard deviation from mean



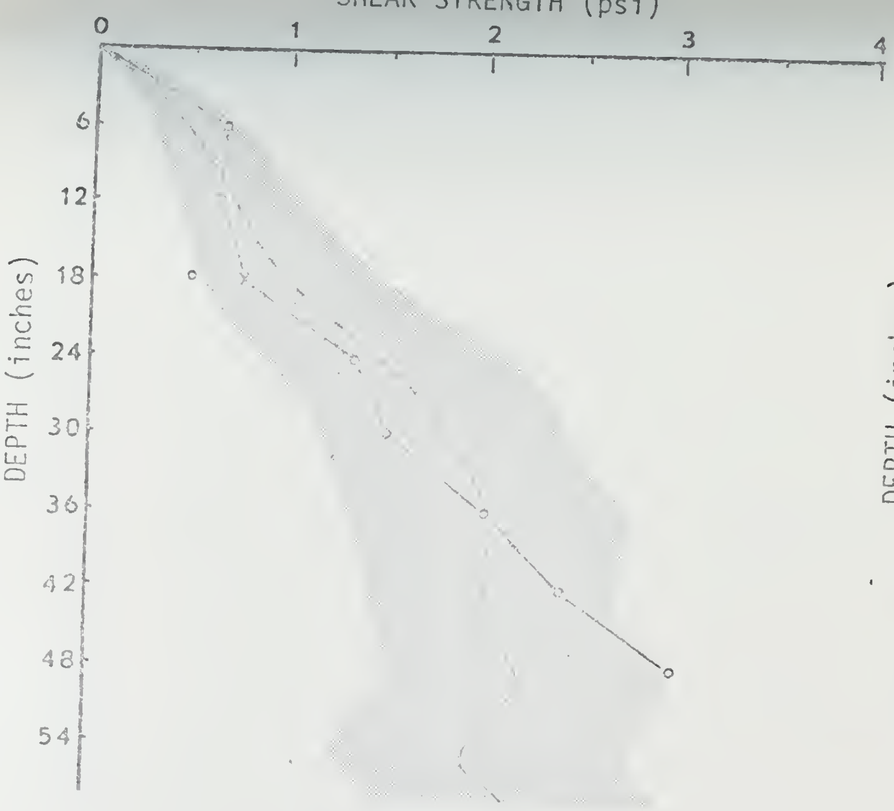
SPHERE
Velocity 20.0 fps
Station 26



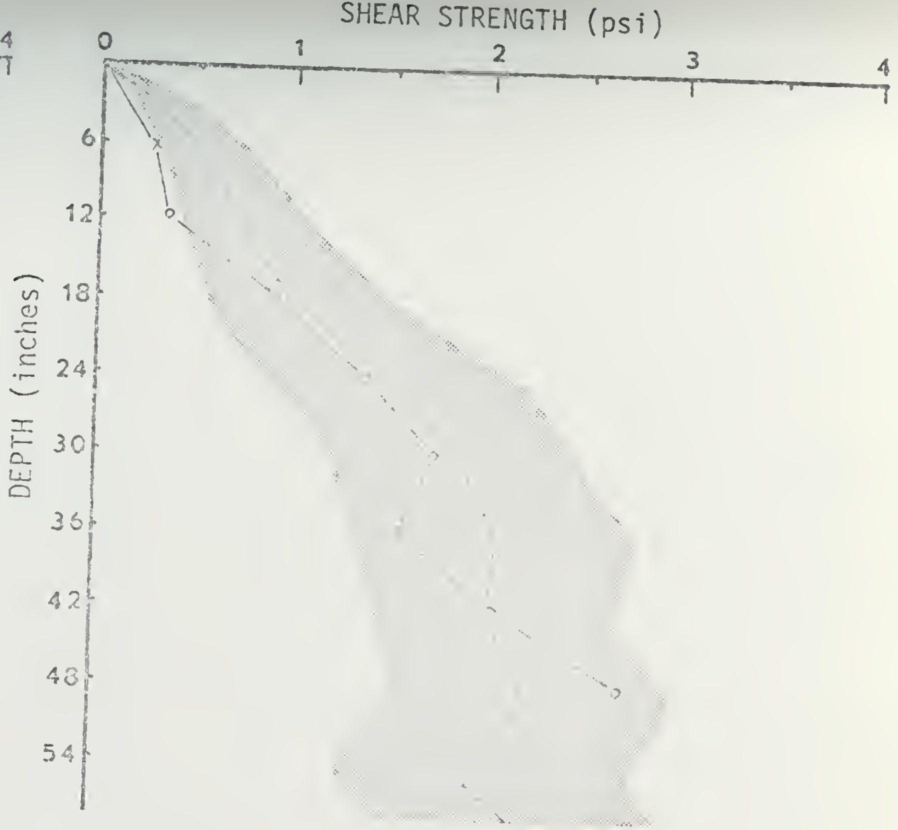
SPHERE
Velocity 5.0 fps
Station 15

○ observed
× adjusted

------ mean
——— shear strength used
▨ one standard deviation from mean



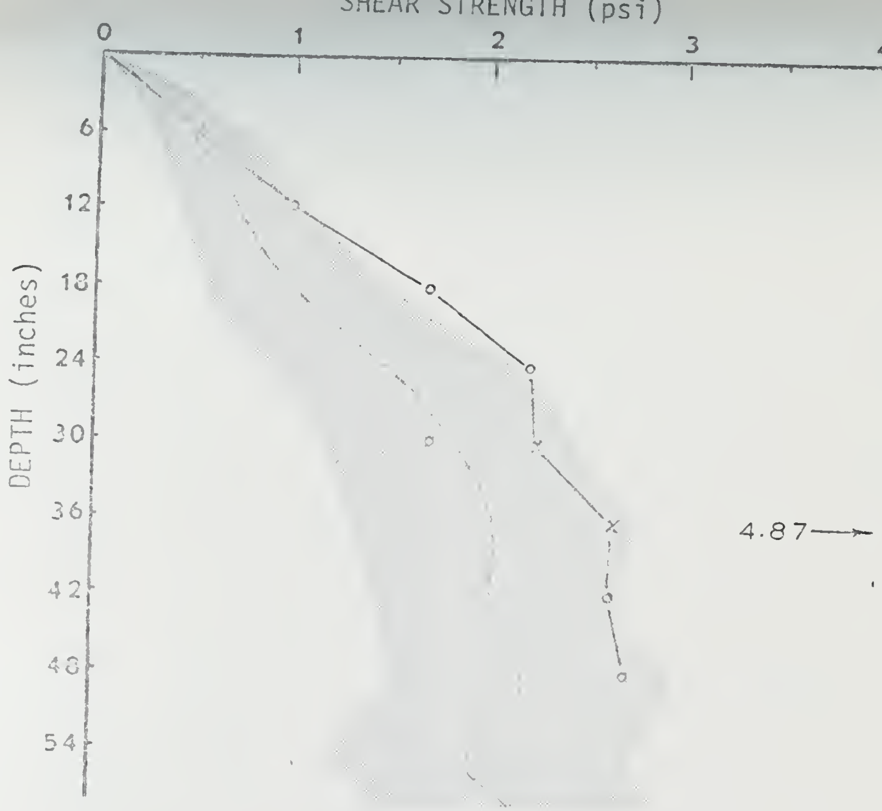
SPHERE
Velocity 10.0 fps
Station -



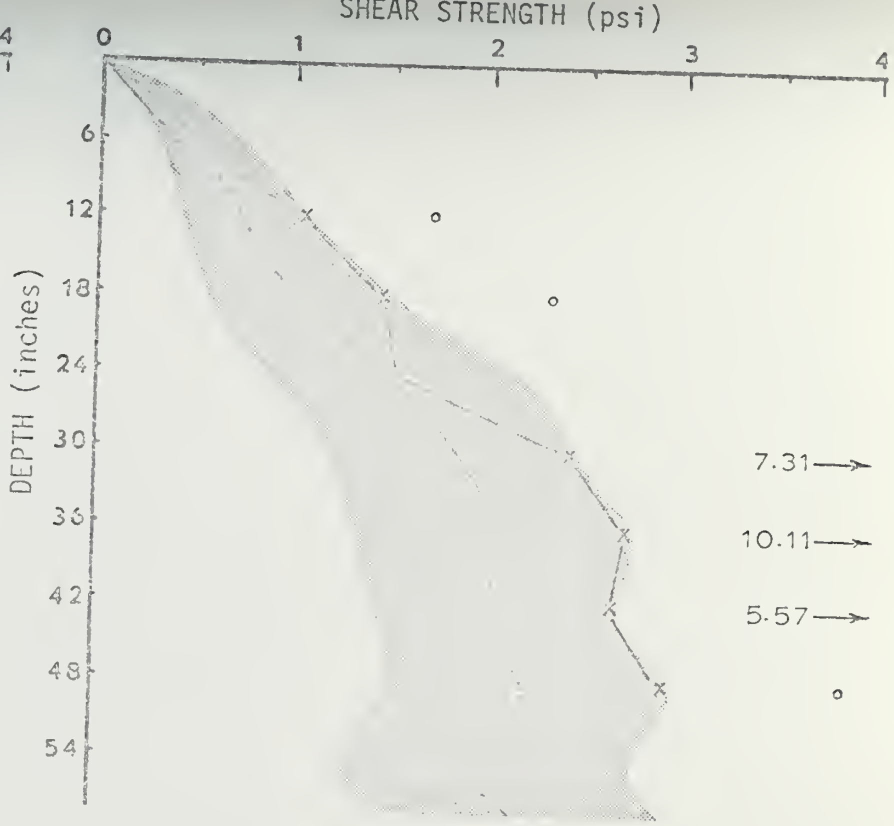
SPHERE
Velocity 15.0 fps
Station -

o observed
x adjusted

------ mean
——— shear strength used
▨ one standard deviation from mean



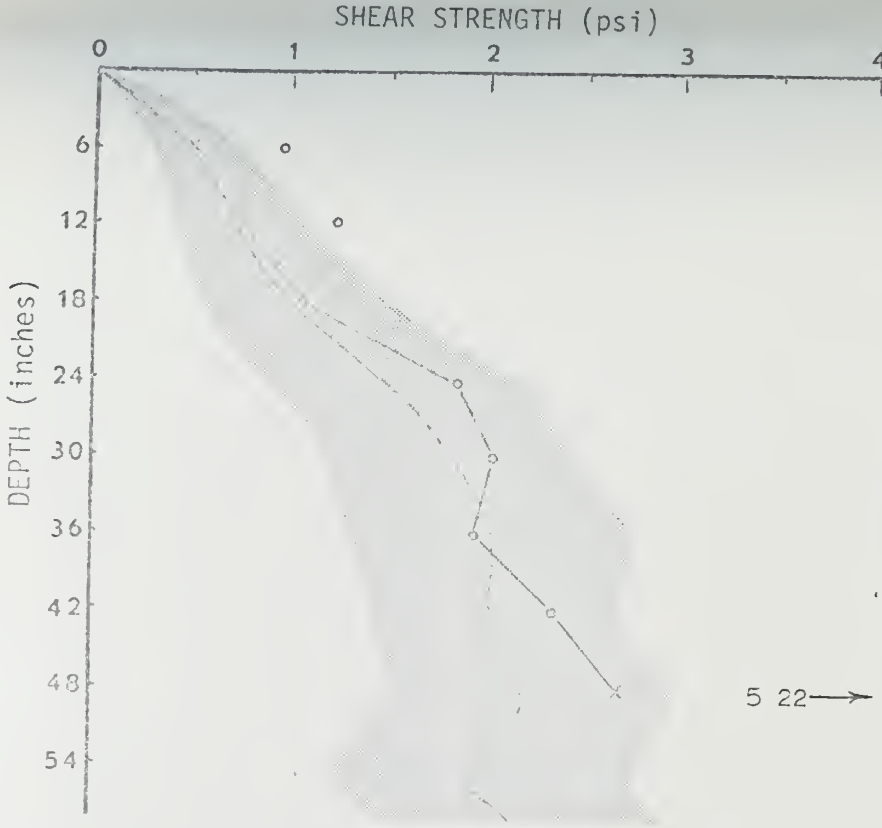
SPHERE
Velocity 20.0 fps
Station -



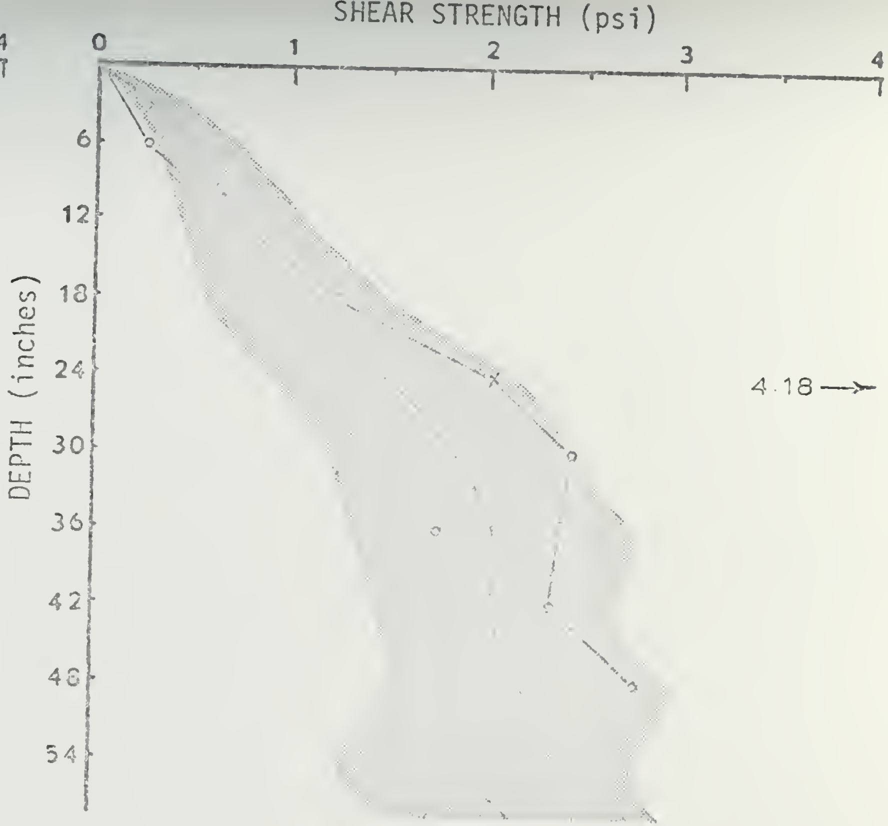
HORIZONTAL CYLINDER
Velocity 0.0 fps
Station 23

○ observed
× adjusted

------ mean ——— shear strength used
▨ one standard deviation from mean

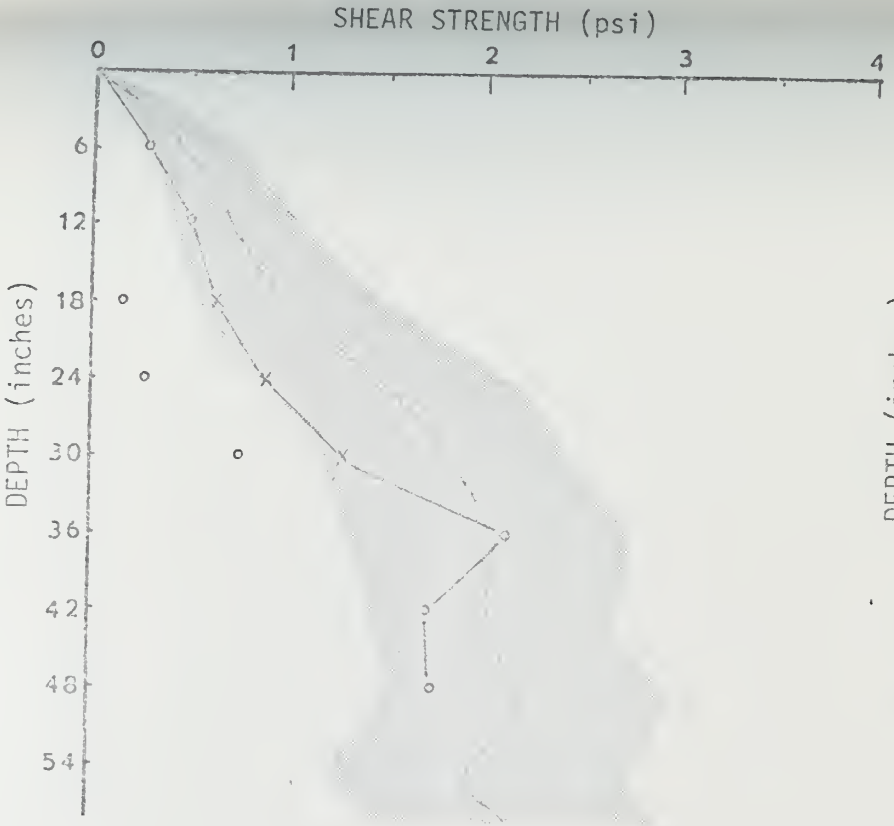


HORIZONTAL CYLINDER
Velocity 5.0 fps
Station 15

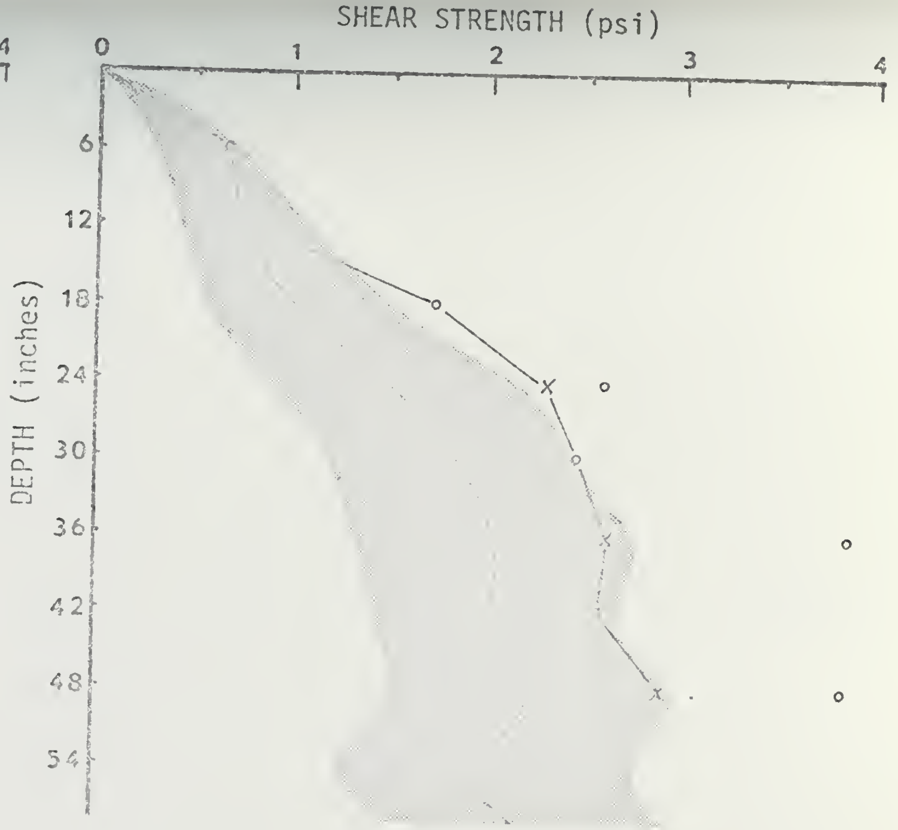


HORIZONTAL CYLINDER
Velocity 10.0 fps
Station 21

○ observed
× adjusted
------ mean
——— shear strength used
▨ one standard deviation from mean



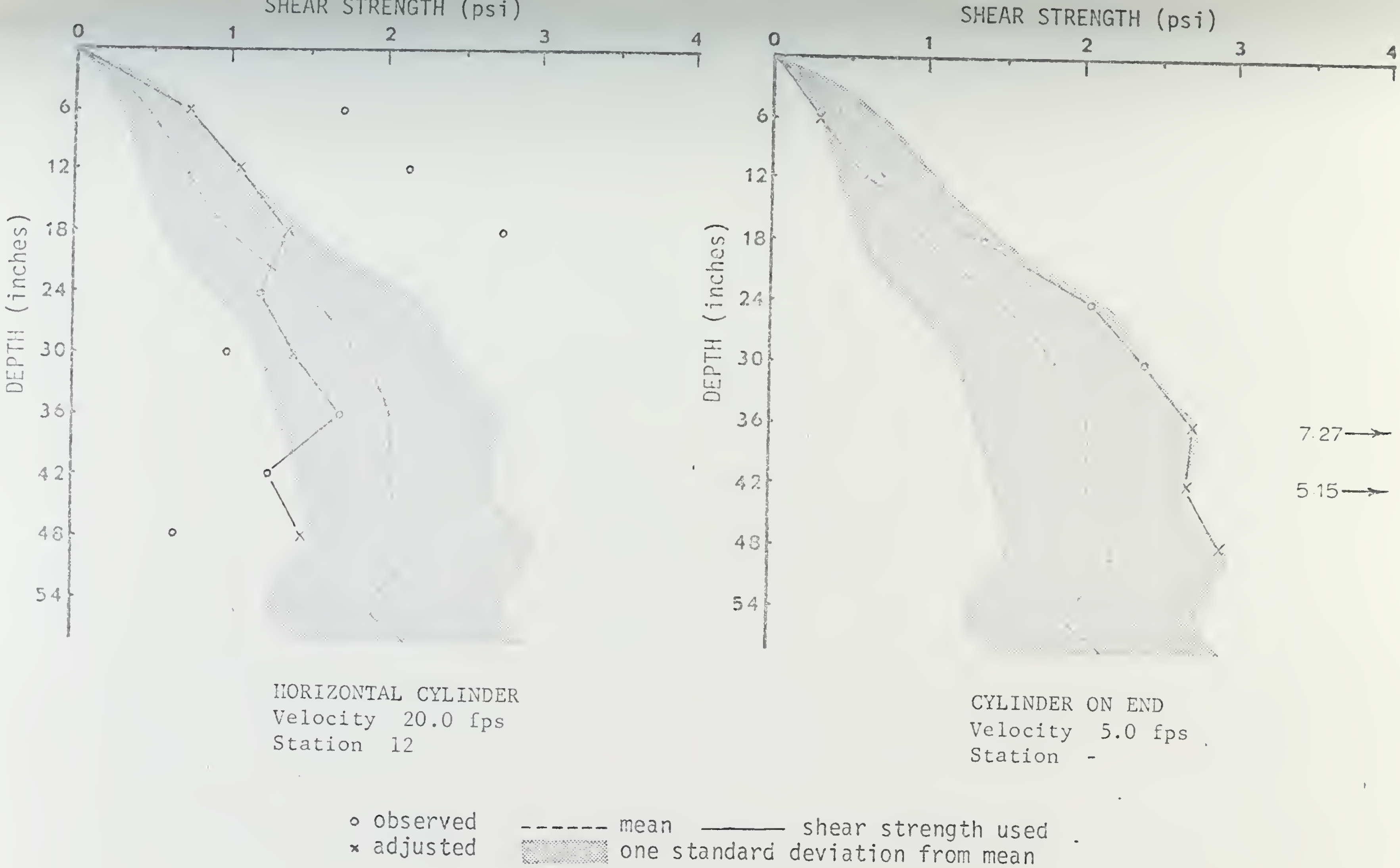
HORIZONTAL CYLINDER
Velocity 15.0 fps
Station 16



HORIZONTAL CYLINDER
Velocity 20.0 fps
Station 22

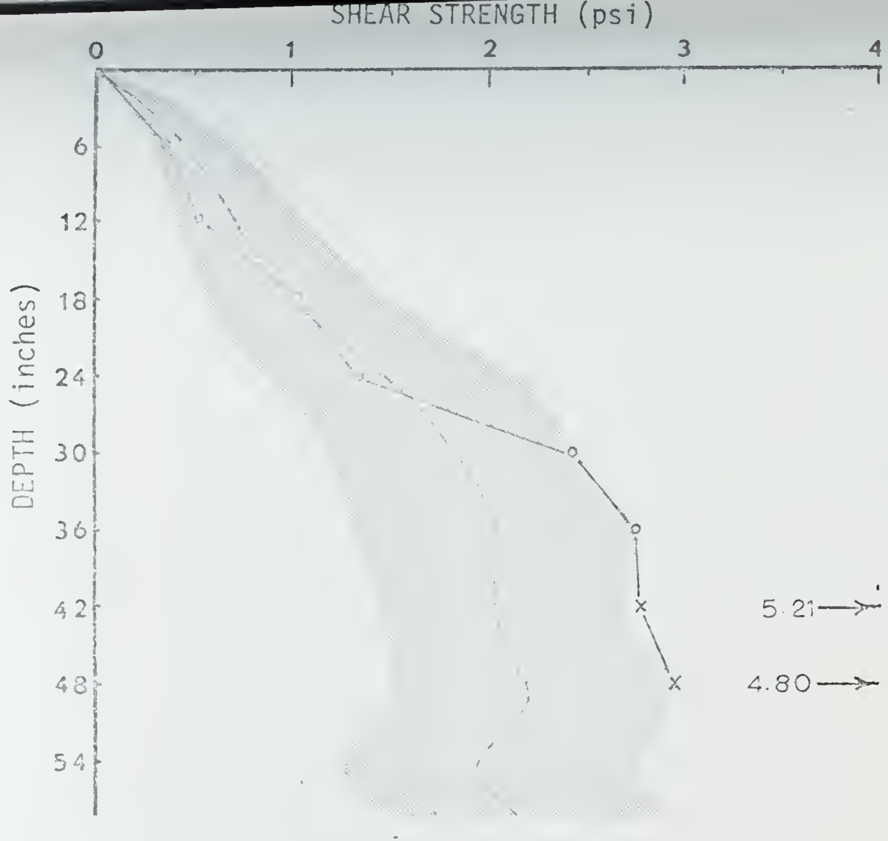
○ observed
× adjusted

------ mean
——— shear strength used
▨ one standard deviation from mean

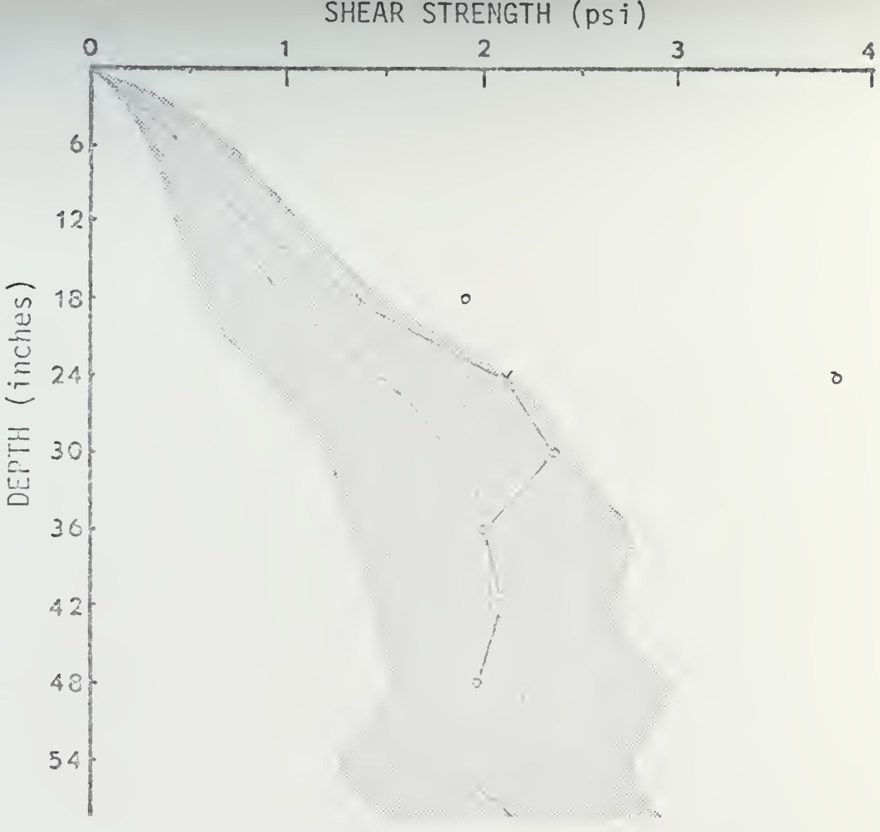


HORIZONTAL CYLINDER
Velocity 20.0 fps
Station 12

CYLINDER ON END
Velocity 5.0 fps
Station -

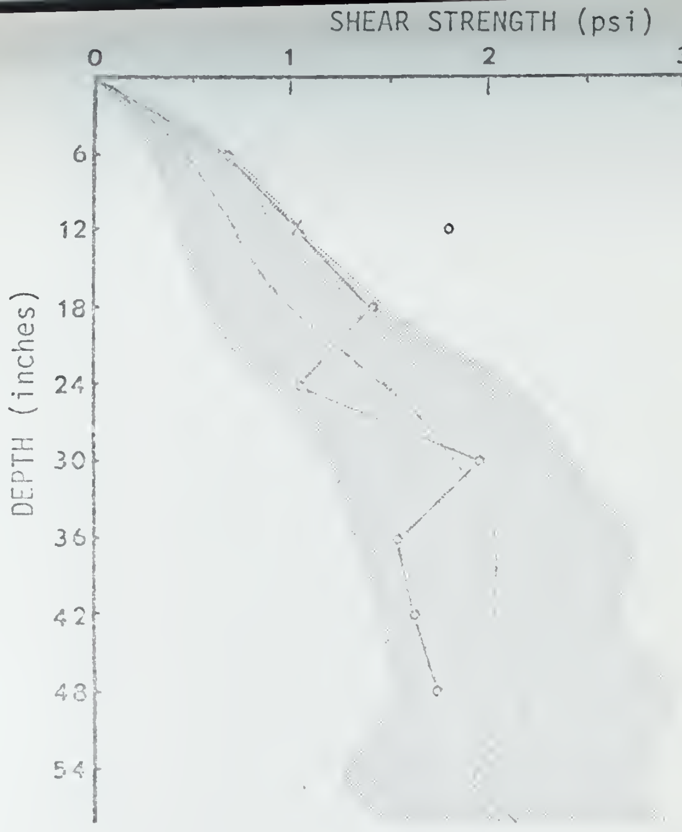


CYLINDER ON END
Velocity 10.0 fps
Station -

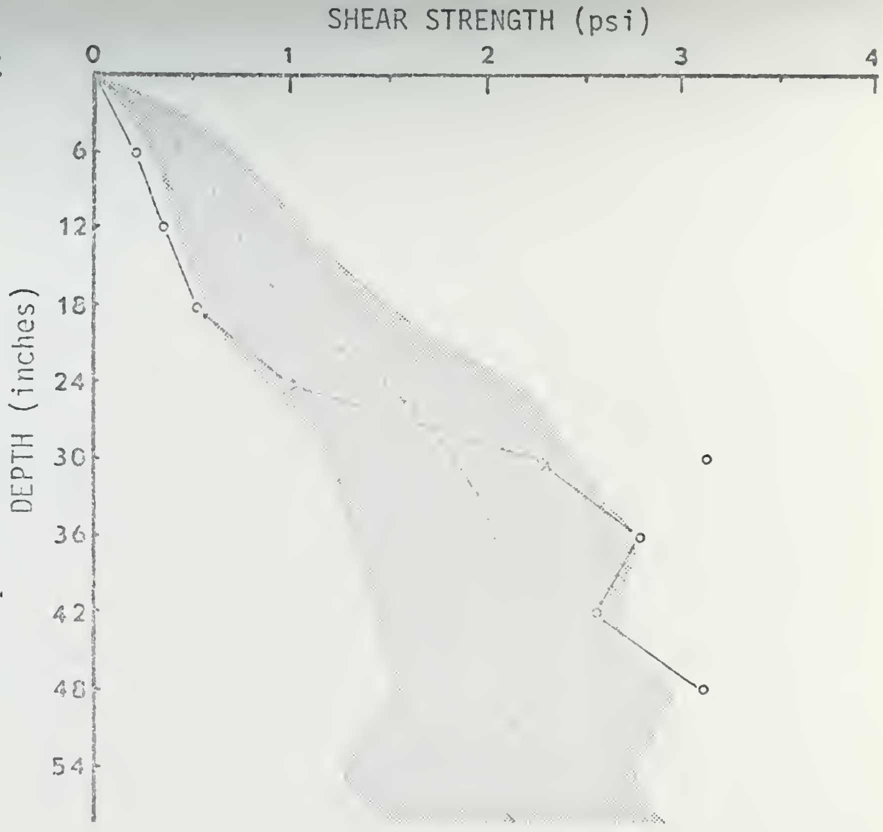


CYLINDER ON END
Velocity 15.0 fps
Station -

o observed	------ mean	——— shear strength used
× adjusted	▨ one standard deviation from mean	

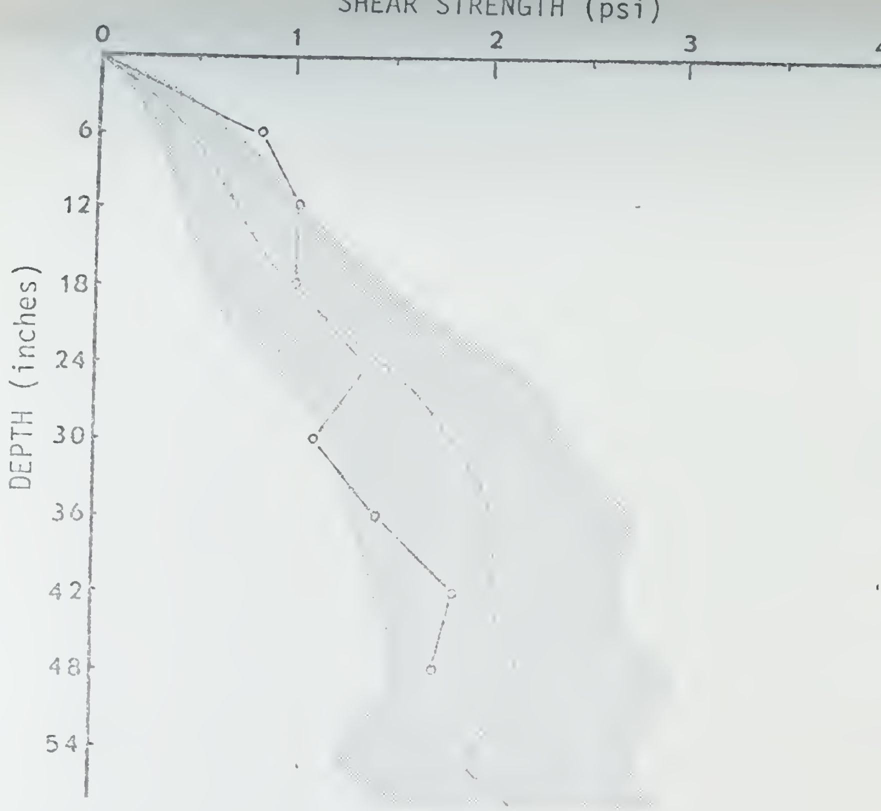


CYLINDER ON END
Velocity 20.0 fps
Station -

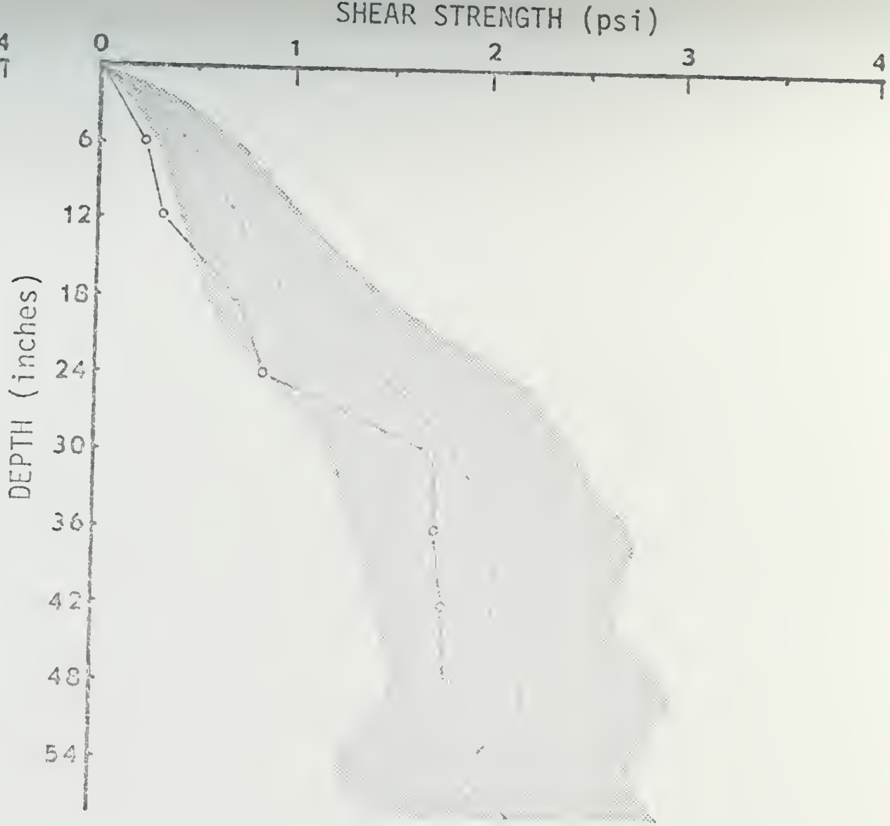


CYLINDER ON END
Velocity 0.0 fps
Station 22

o observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean



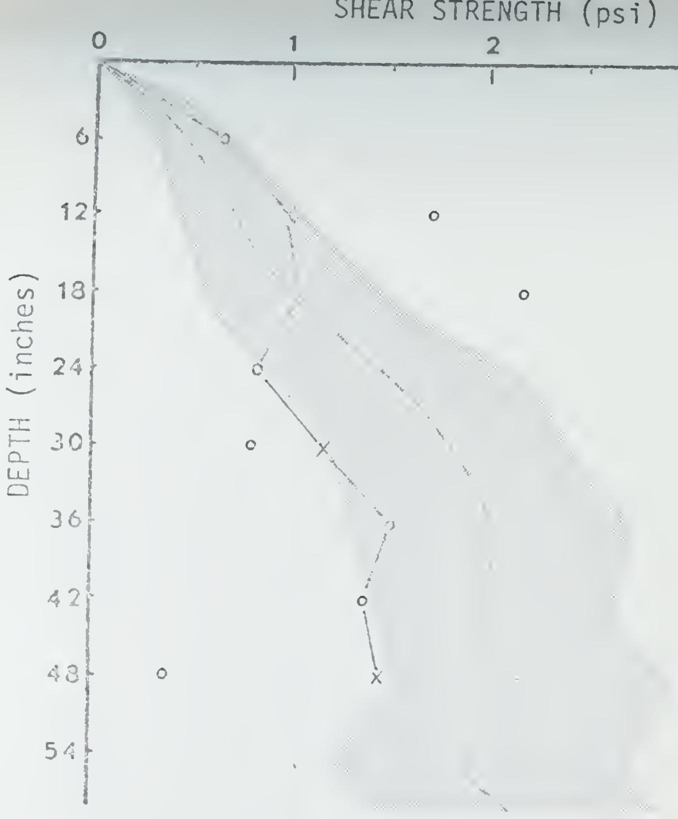
CYLINDER ON END
Velocity 5.0 fps
Station 14



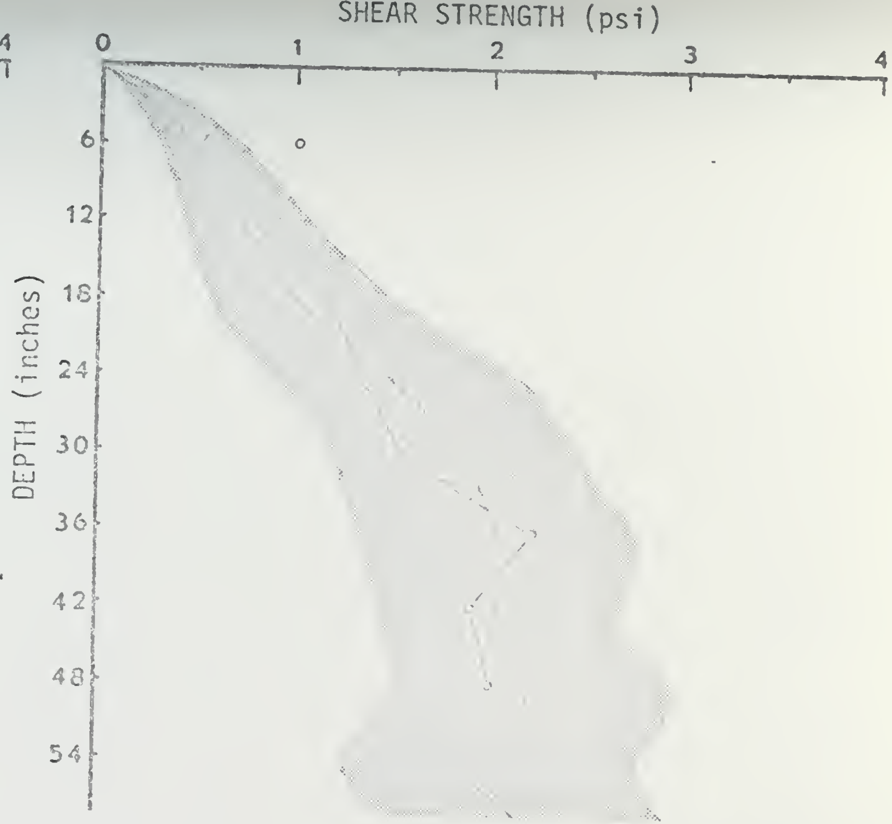
CYLINDER ON END
Velocity 10.0 fps
Station 16

o observed
× adjusted

------ mean
——— shear strength used
▨ one standard deviation from mean

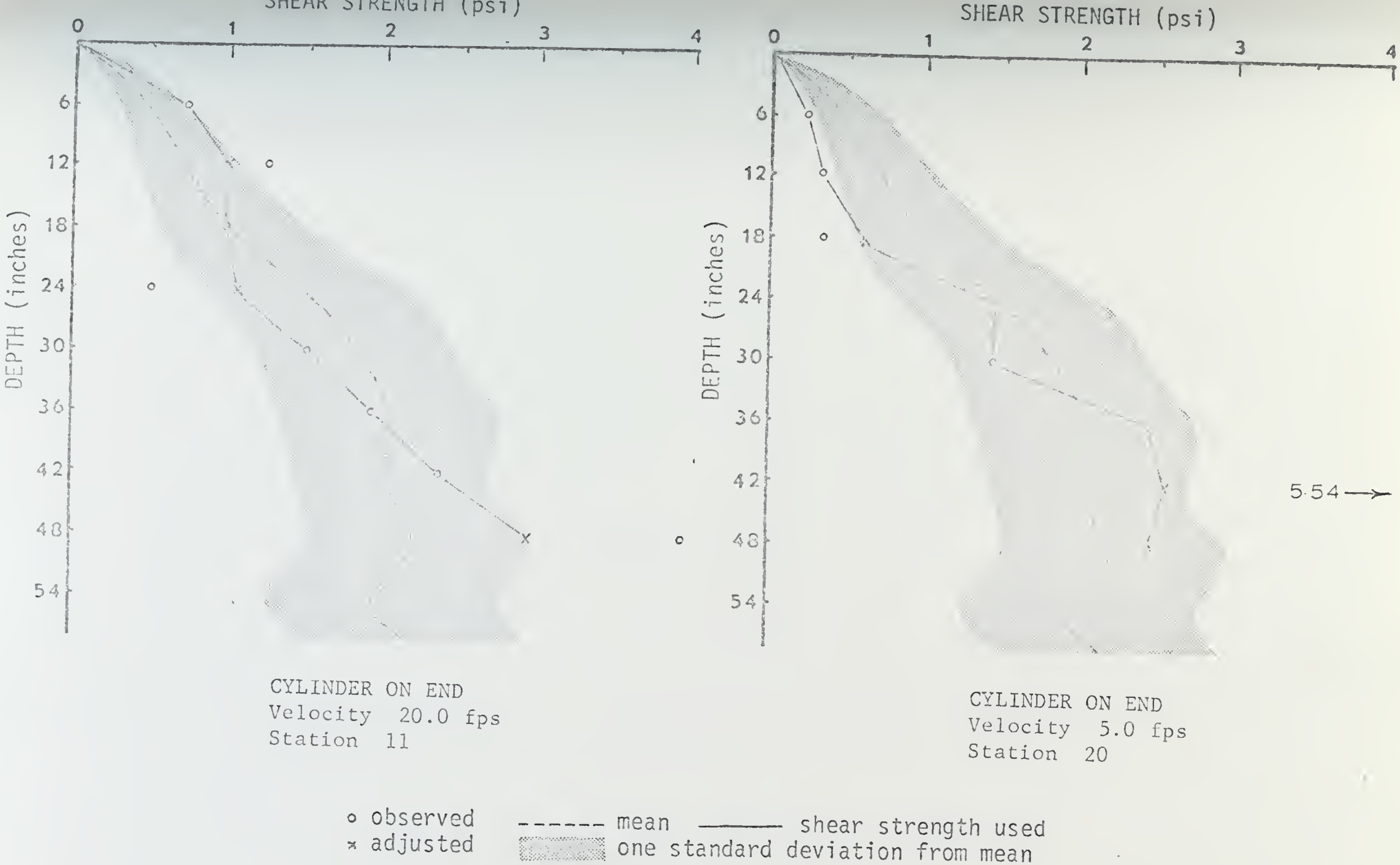


CYLINDER ON END
Velocity 15.0 fps
Station 12



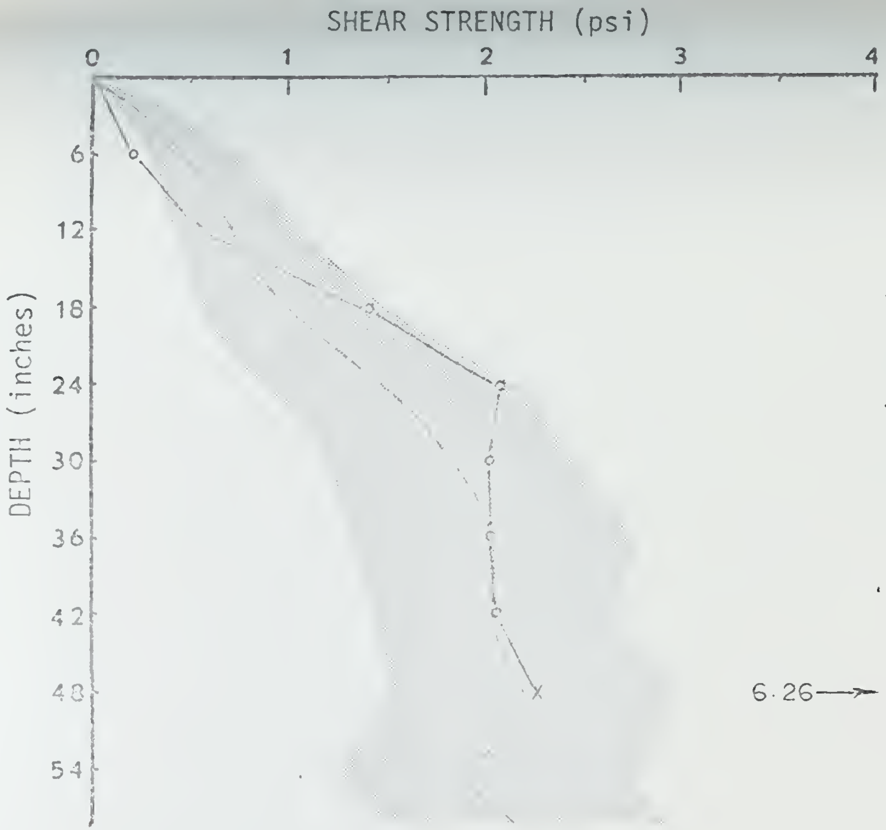
CYLINDER ON END
Velocity 15.0 fps
Station 21

o observed	------ mean ——— shear strength used
× adjusted	▨ one standard deviation from mean

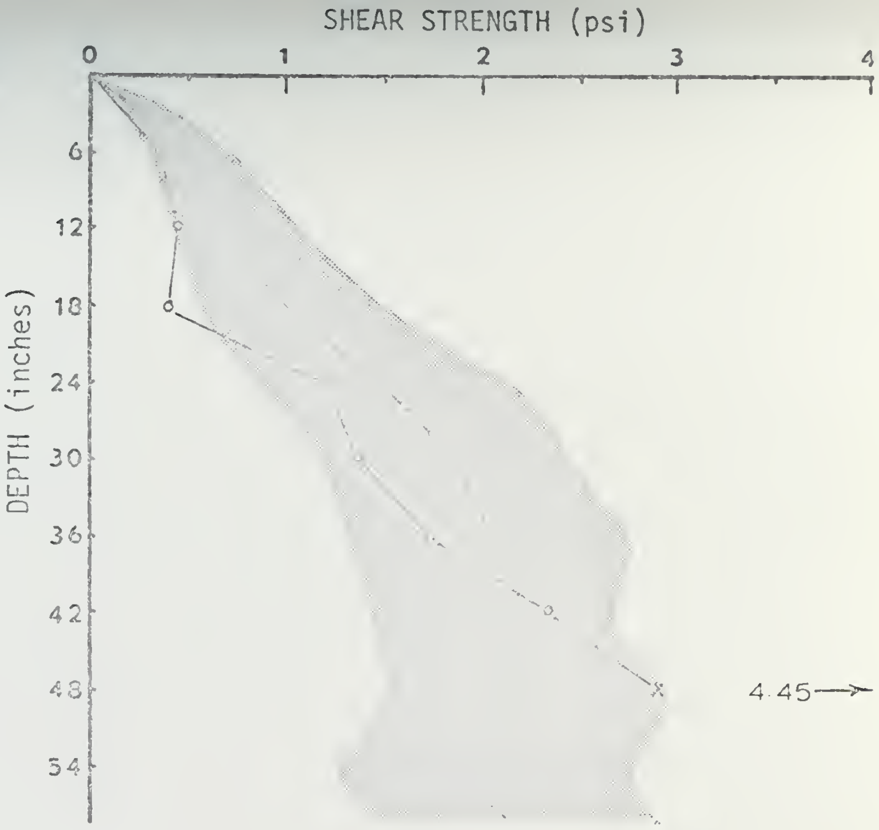


CYLINDER ON END
Velocity 20.0 fps
Station 11

CYLINDER ON END
Velocity 5.0 fps
Station 20

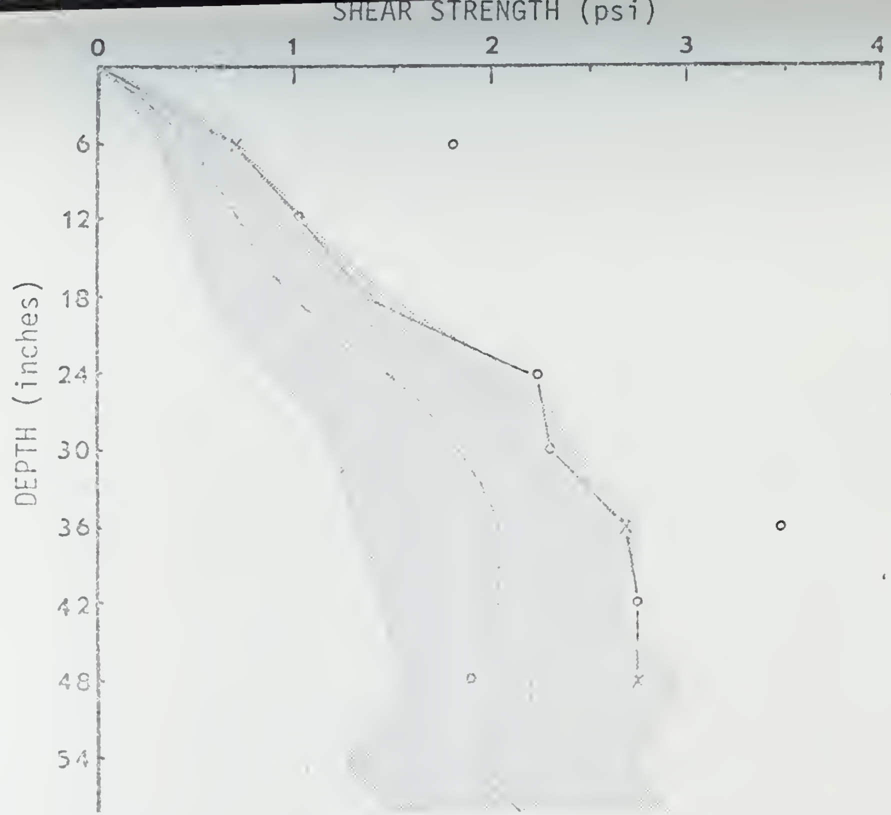


CYLINDER ON END
Velocity 10.0 fps
Station 25

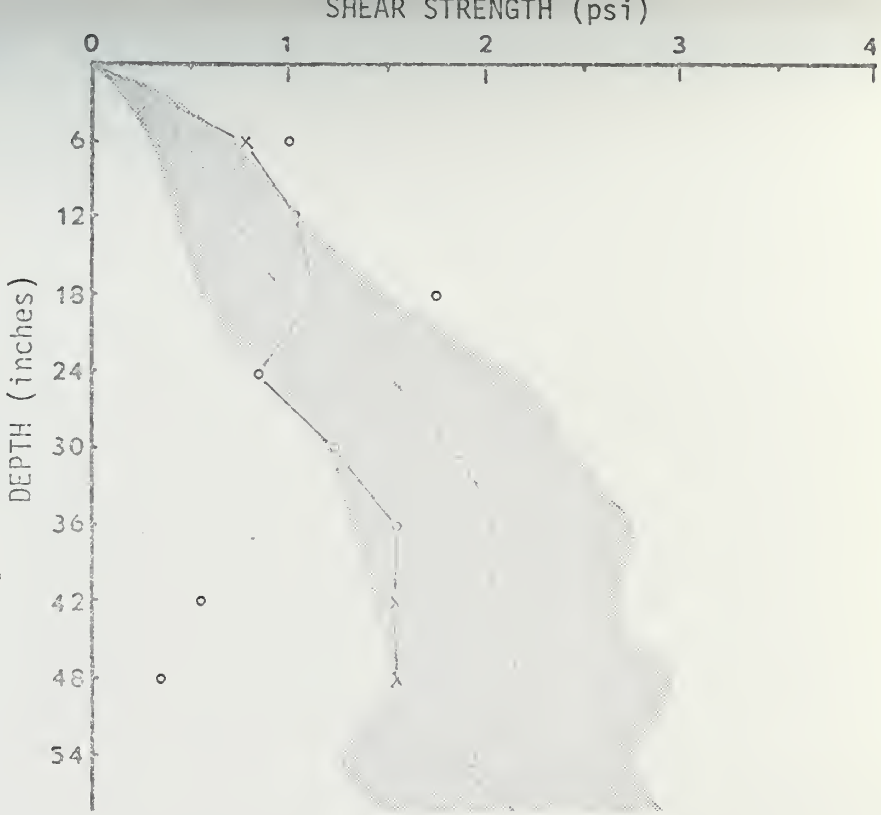


CYLINDER ON END
Velocity 15.0 fps
Station 19

∘ observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

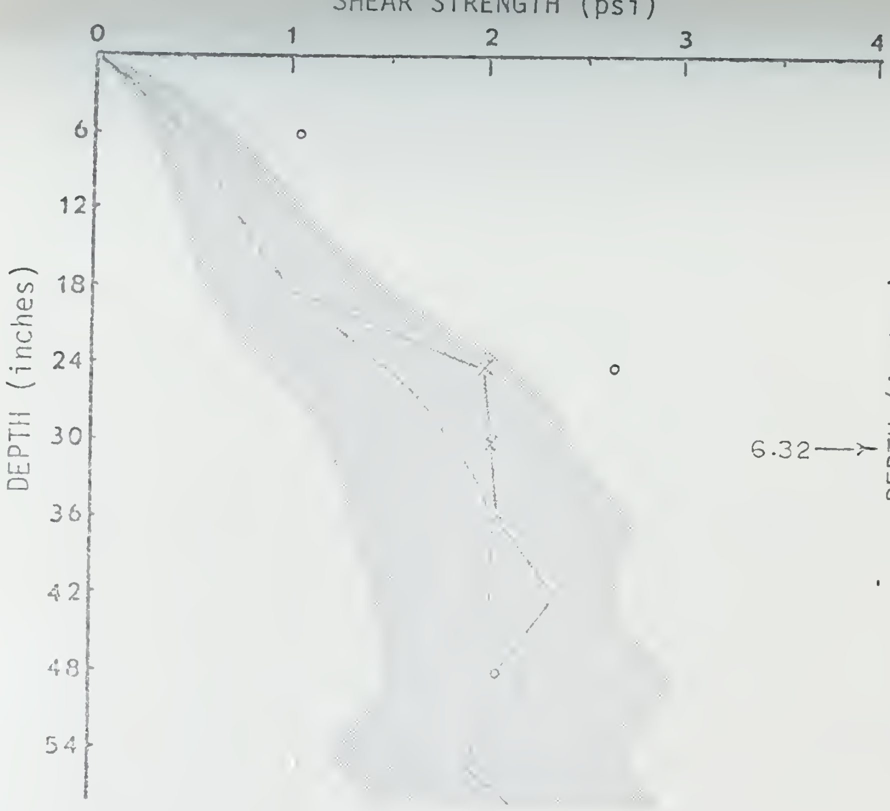


CYLINDER ON END
Velocity 20.0 fps
Station 35

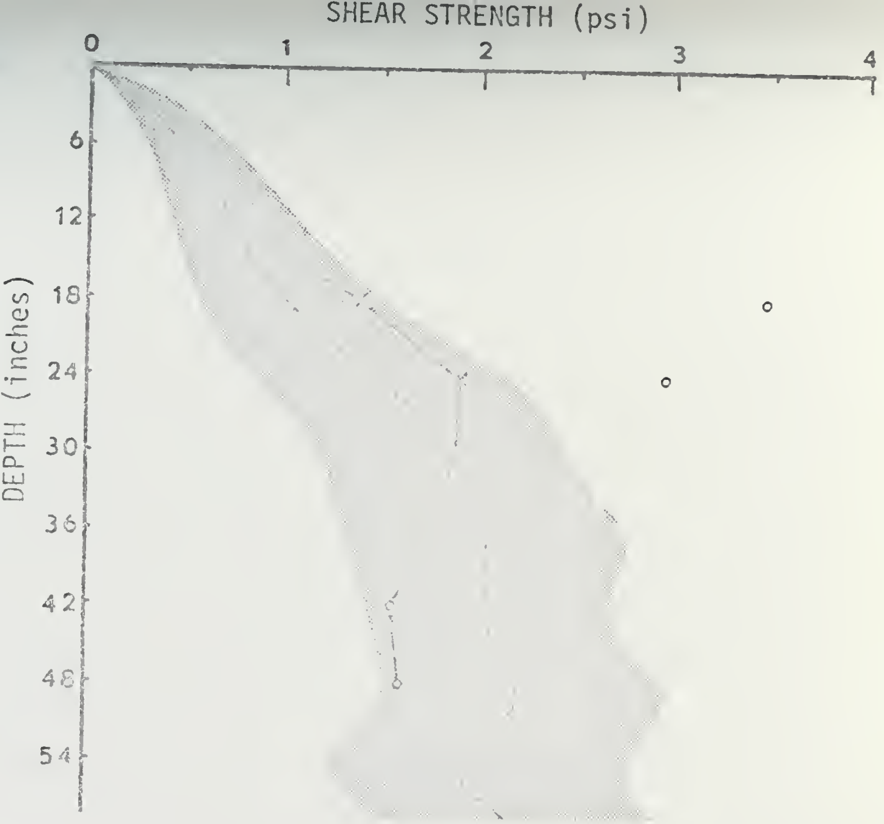


CUBE
Velocity 5.0 fps
Station -

o observed	------ mean ——— shear strength used
× adjusted	▨ one standard deviation from mean

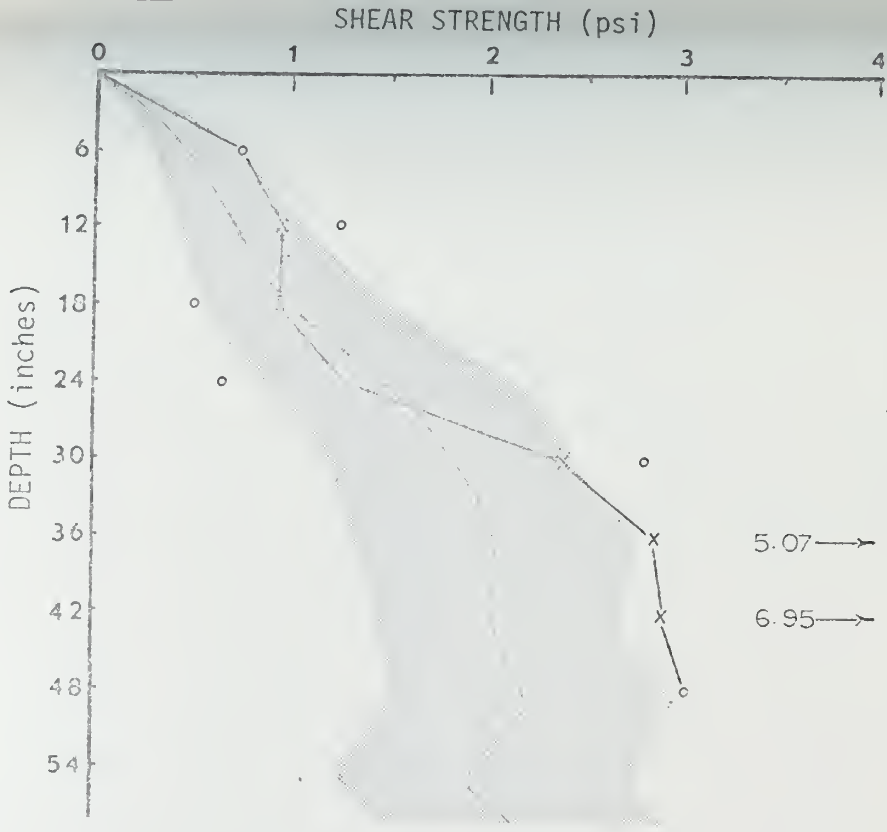


CUBE
Velocity 10.0 fps
Station -

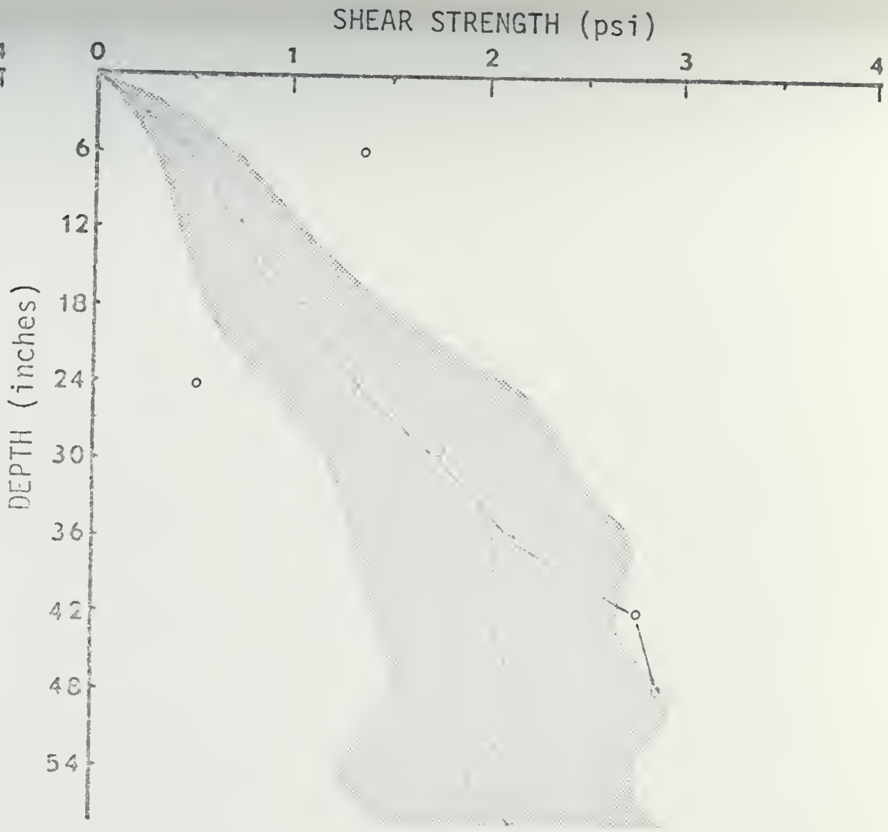


CUBE
Velocity 15.0 fps
Station -

o observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

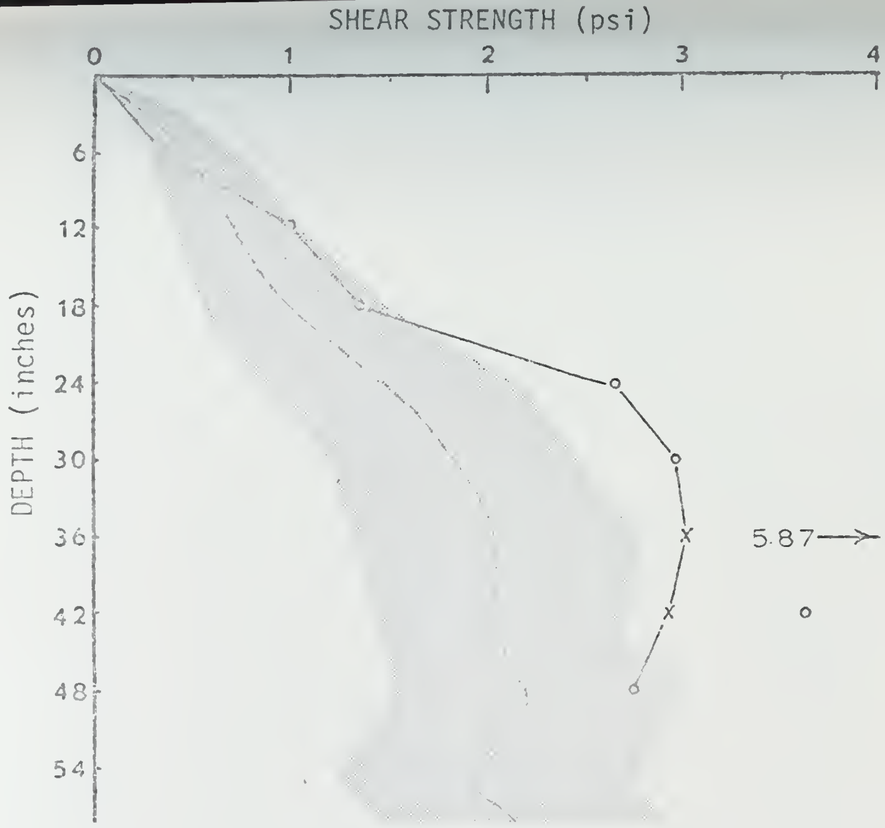


CUBE
Velocity 20.0 fps
Station -

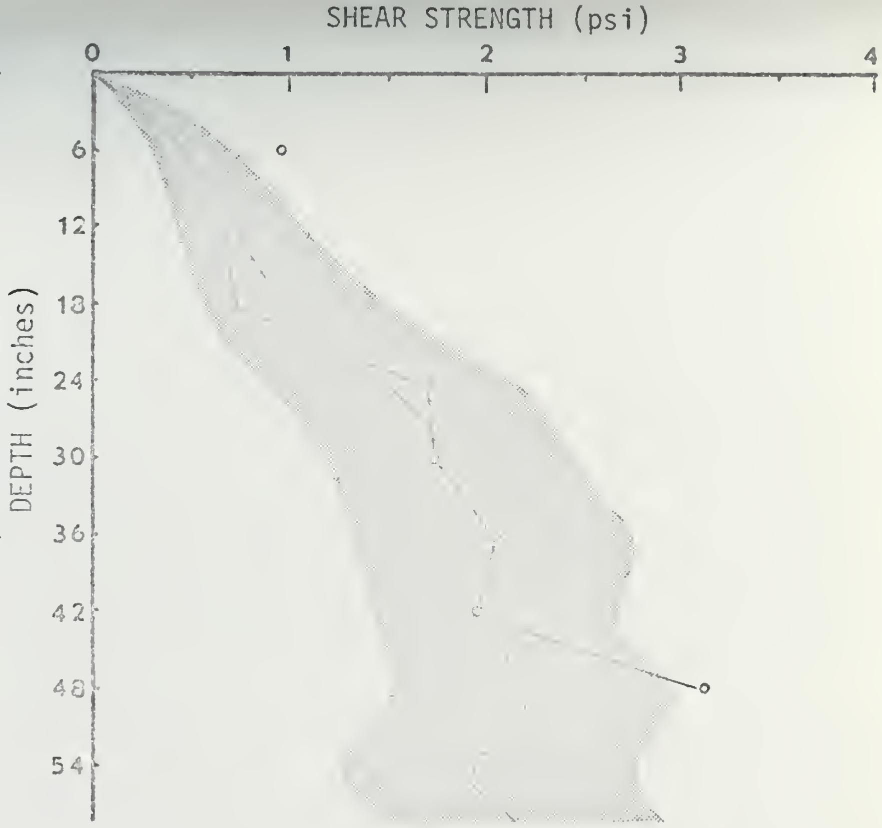


RECTANGLE
Velocity 0.0 fps
Station 24

○ observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

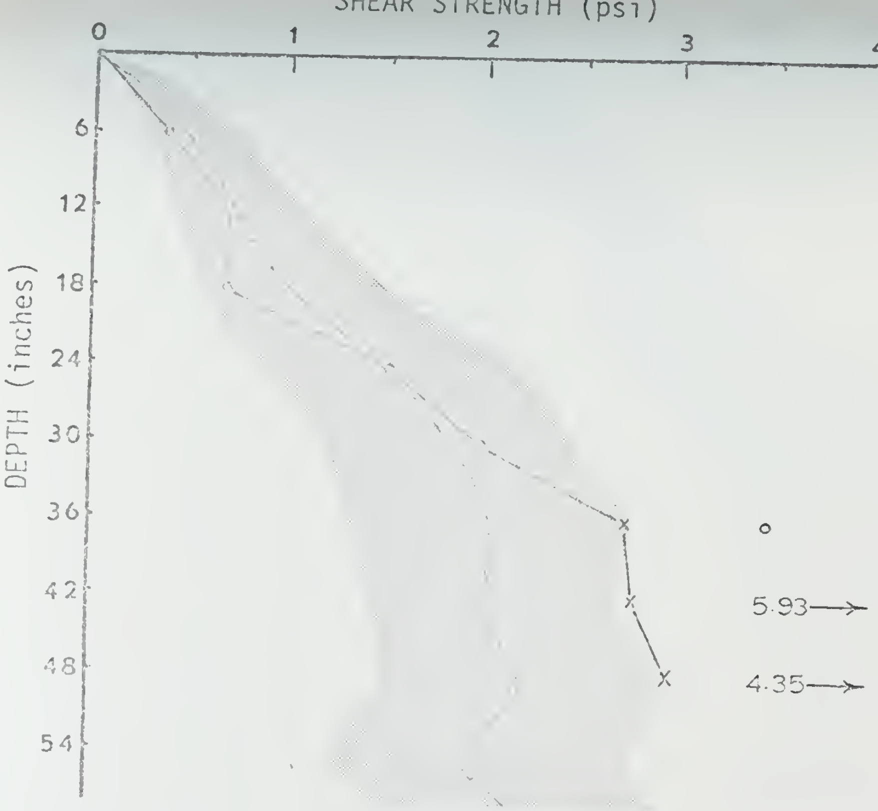


RECTANGLE
Velocity 5.0 fps
Station 13

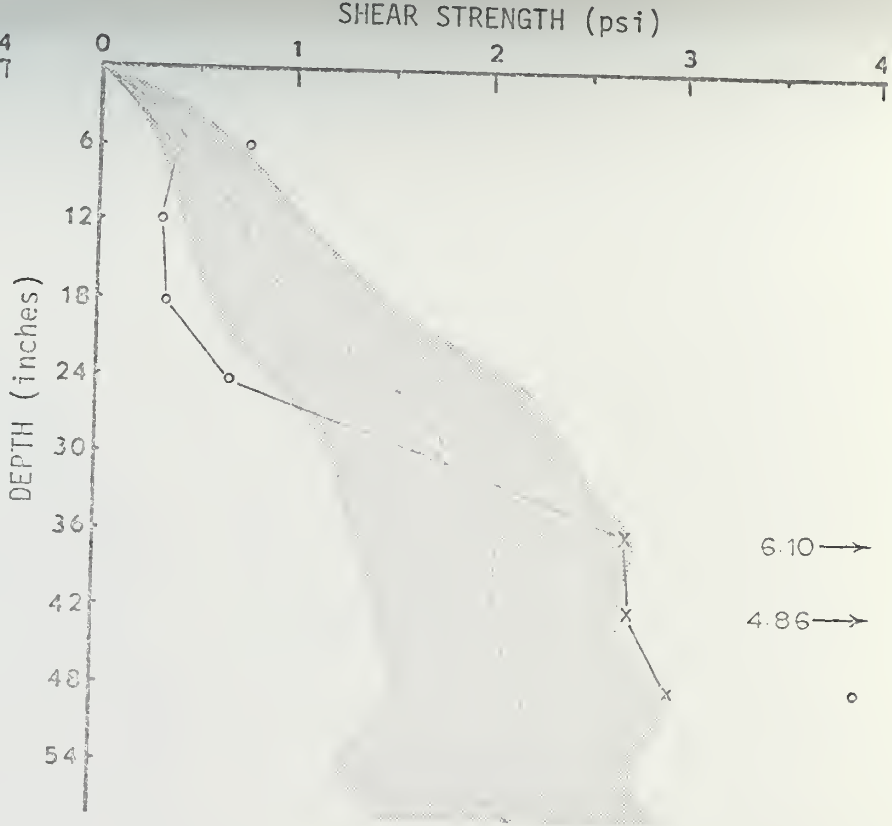


RECTANGLE
Velocity 10.0 fps
Station 11

○ observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

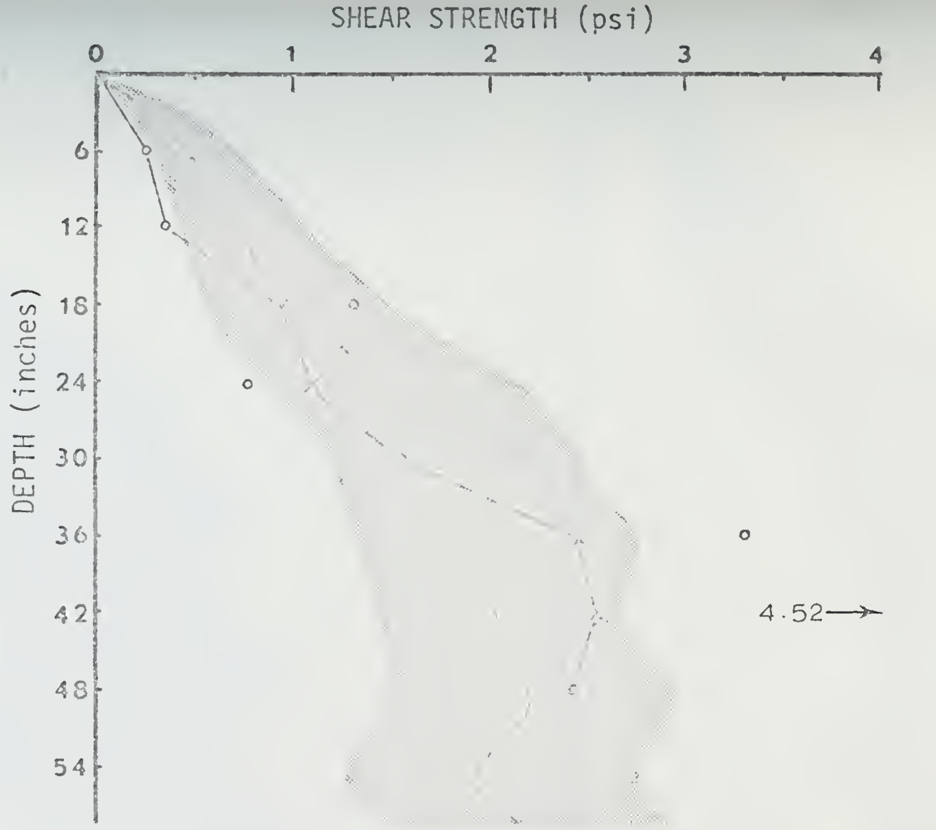


RECTANGLE
Velocity 15.0 fps
Station 17



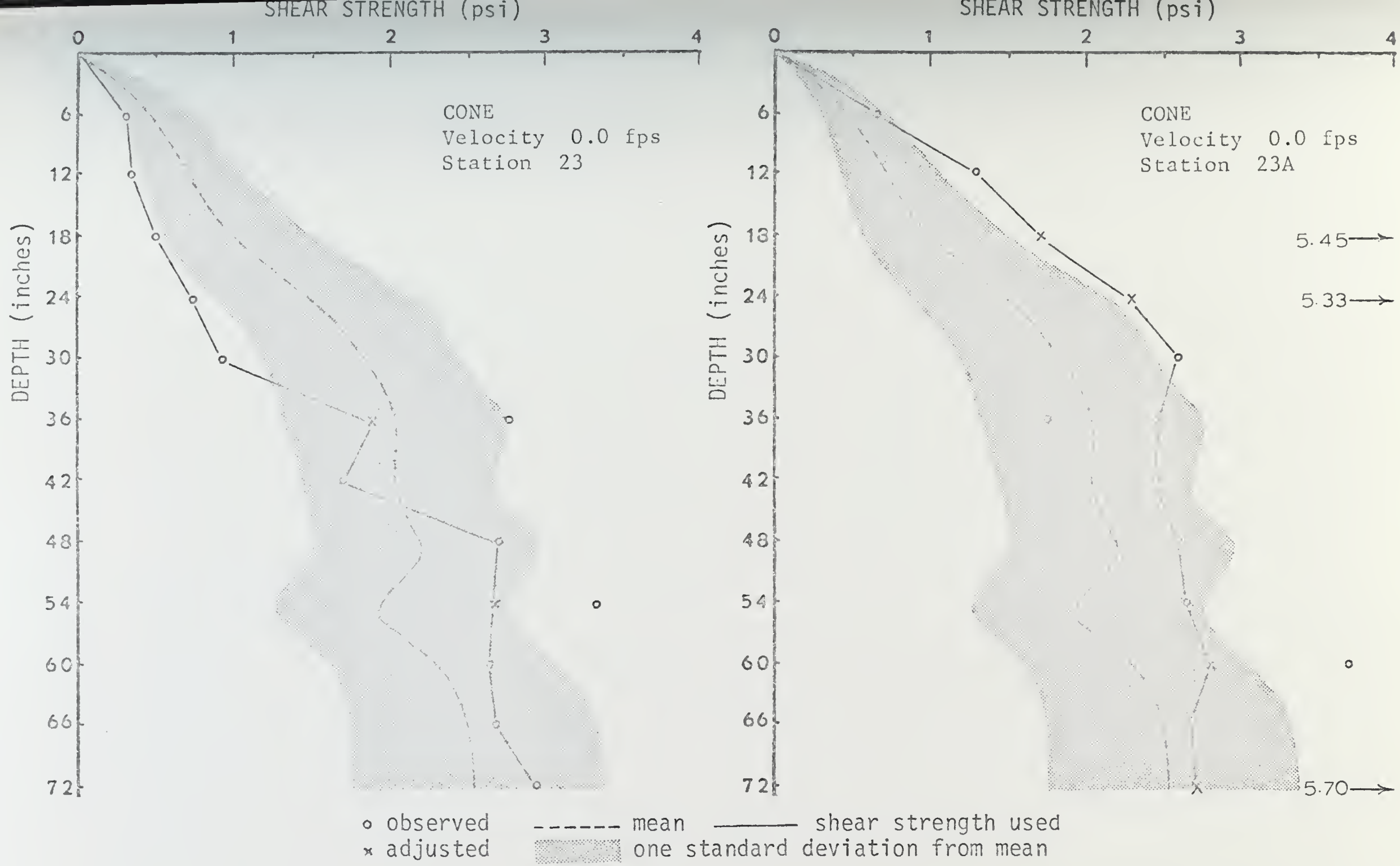
RECTANGLE
Velocity 15.0 fps
Station 19

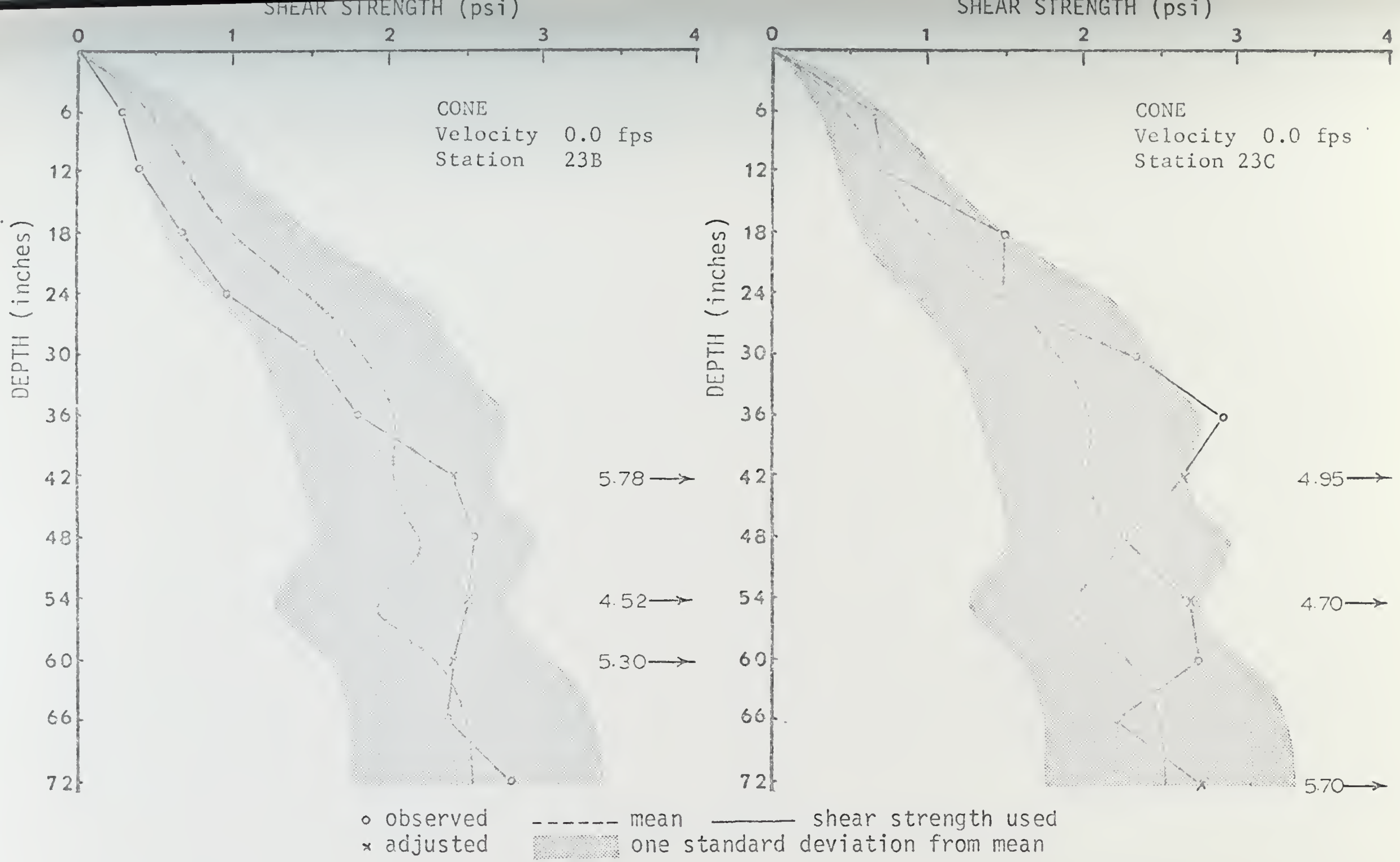
○ observed
× adjusted
------ mean
——— shear strength used
▨ one standard deviation from mean

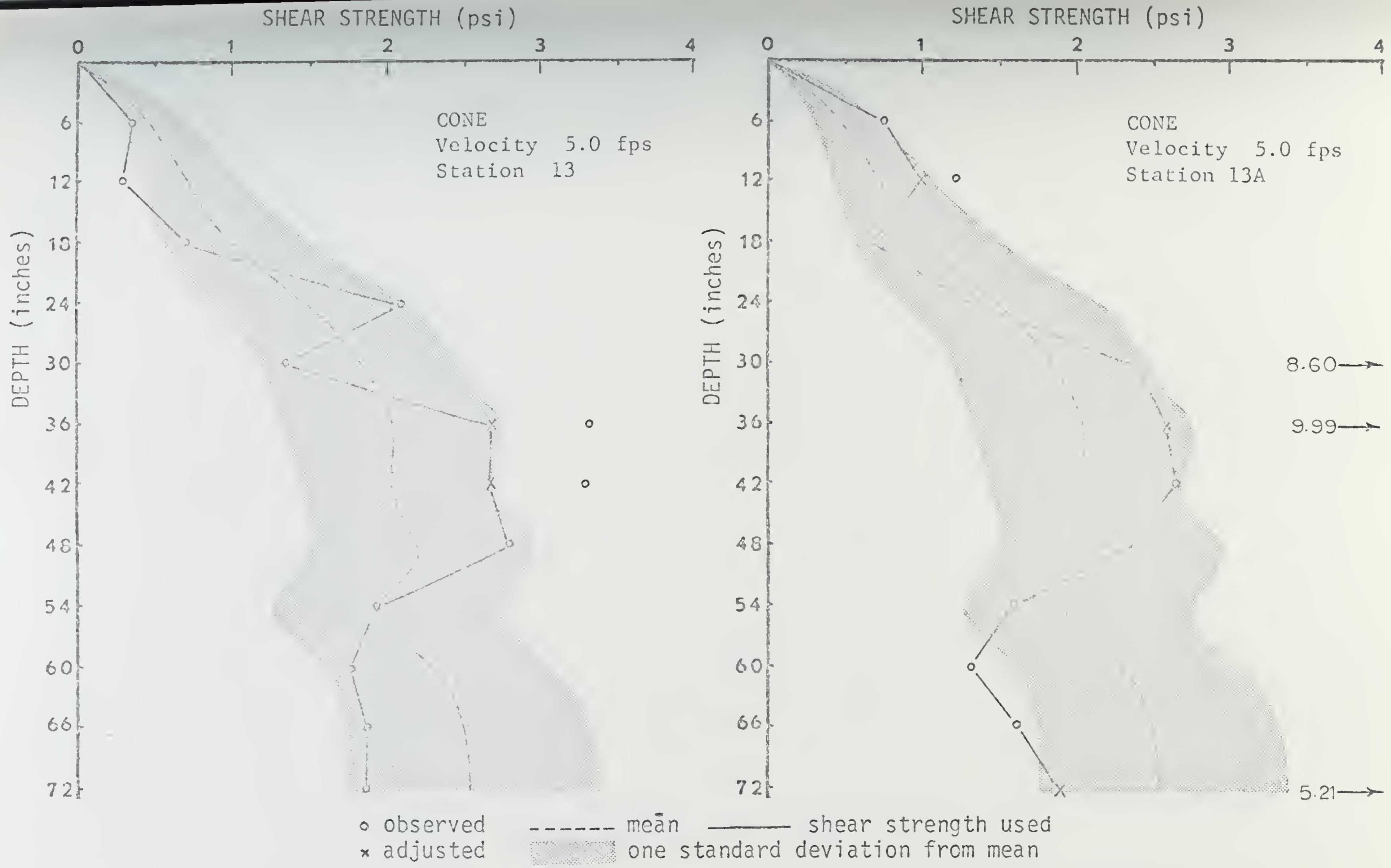


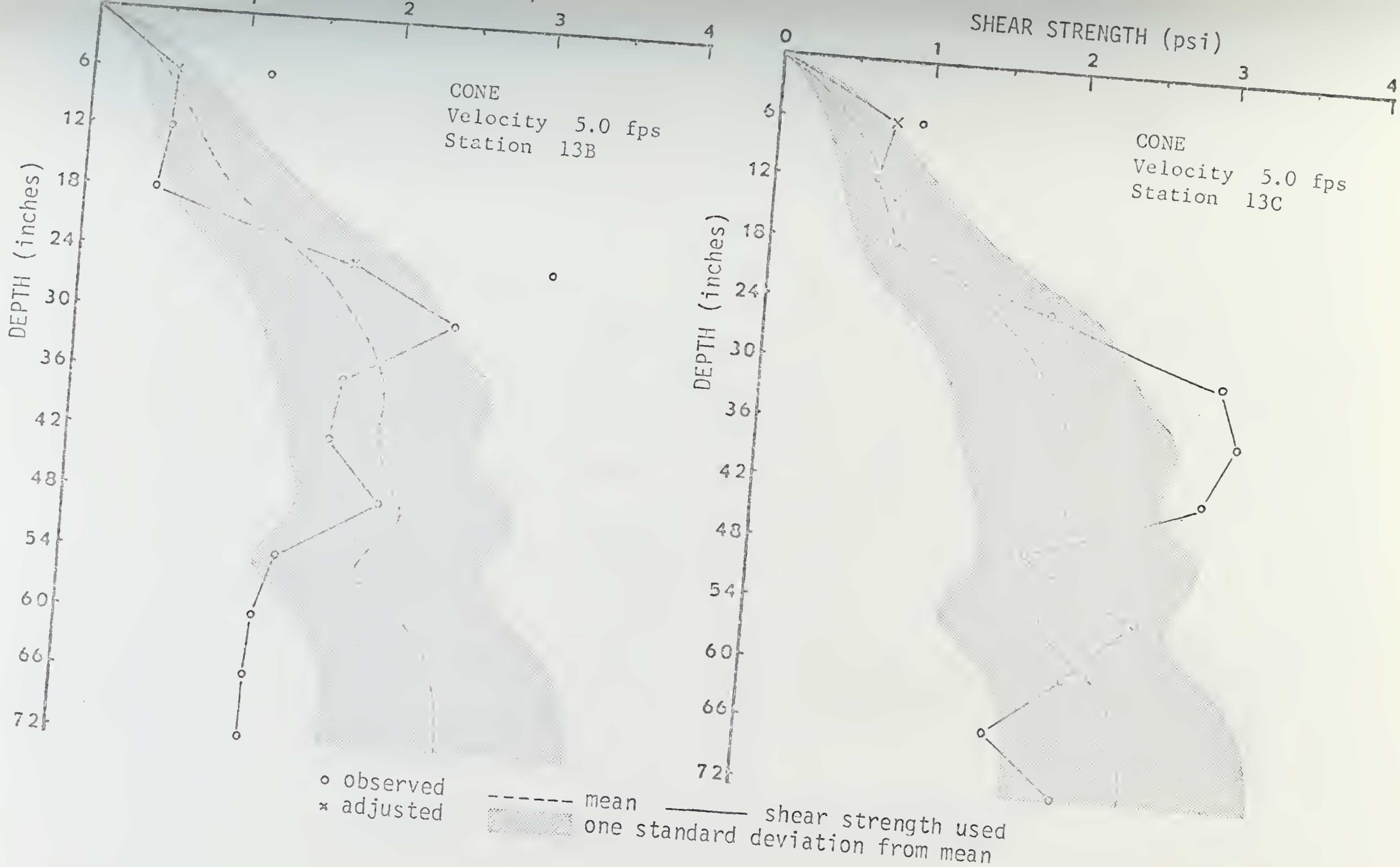
RECTANGLE
Velocity 20.0 fps
Station 18

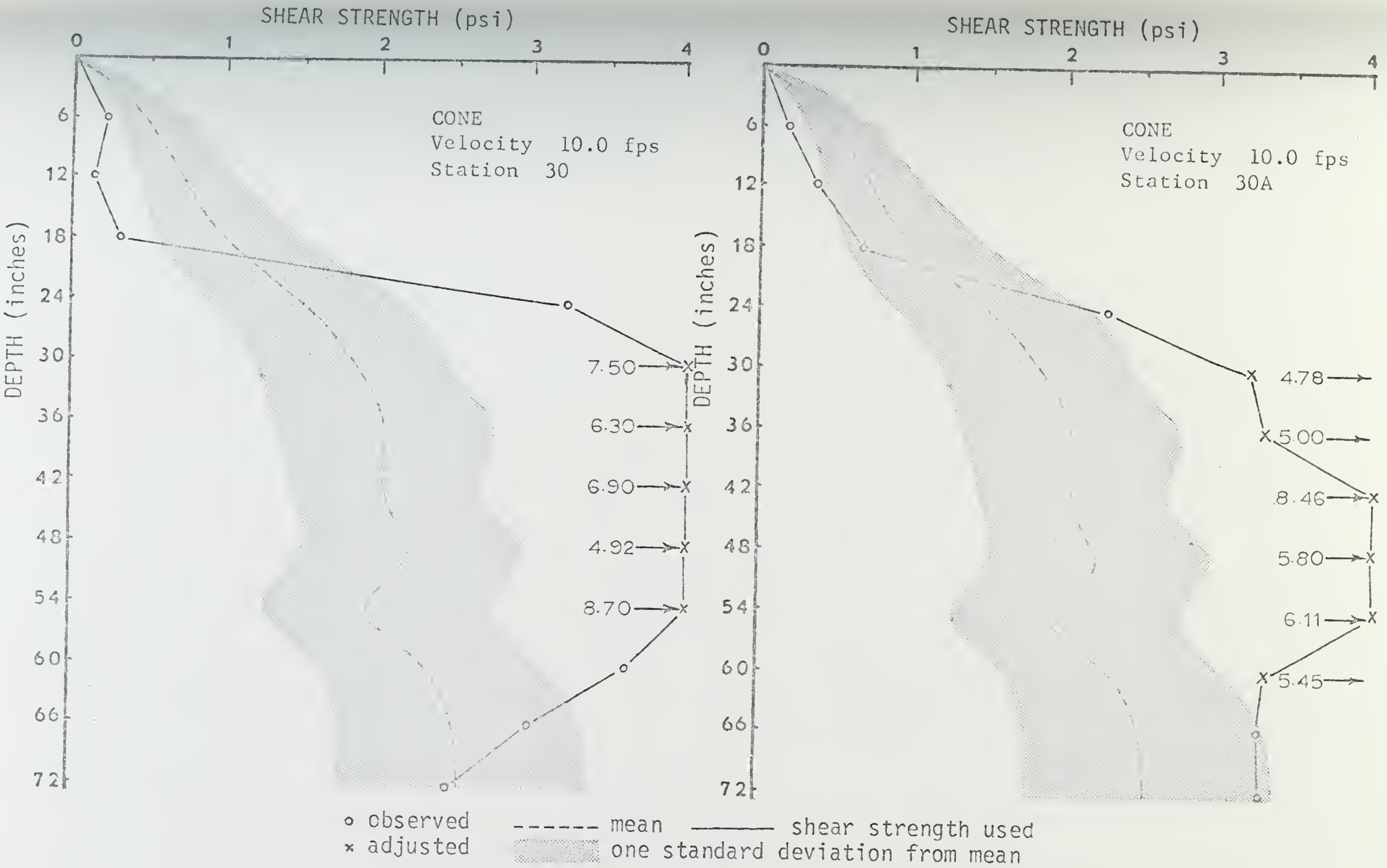
○ observed ------ mean ——— shear strength used
× adjusted ▨ one standard deviation from mean

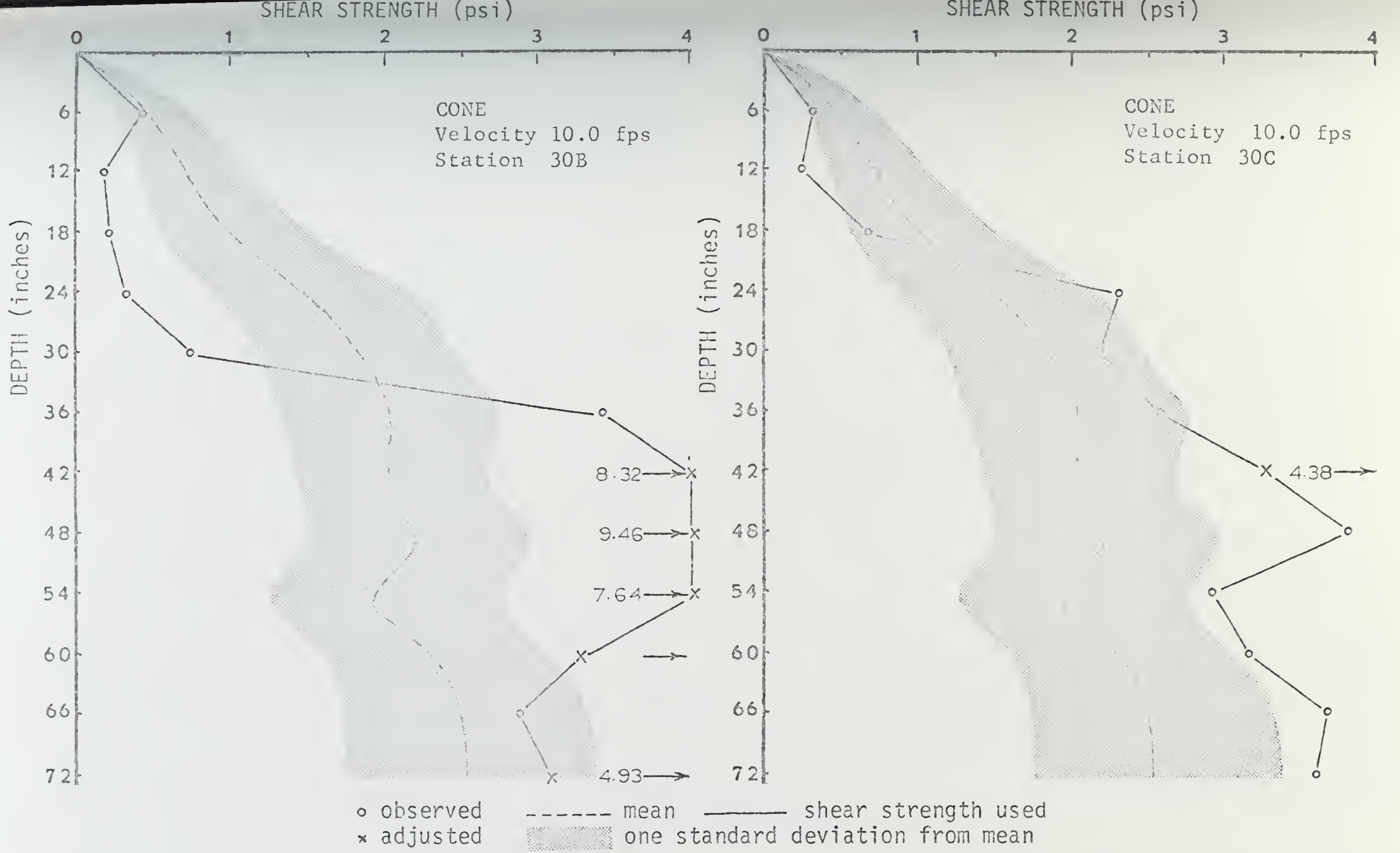

SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 0.0 fps
Station 23
SHEAR STRENGTH (psi)
CONE
Velocity 0.0 fps
Station 23A
5.45
5.33
5.70
○ observed
× adjusted
------ mean
—— shear strength used
▨ one standard deviation from mean

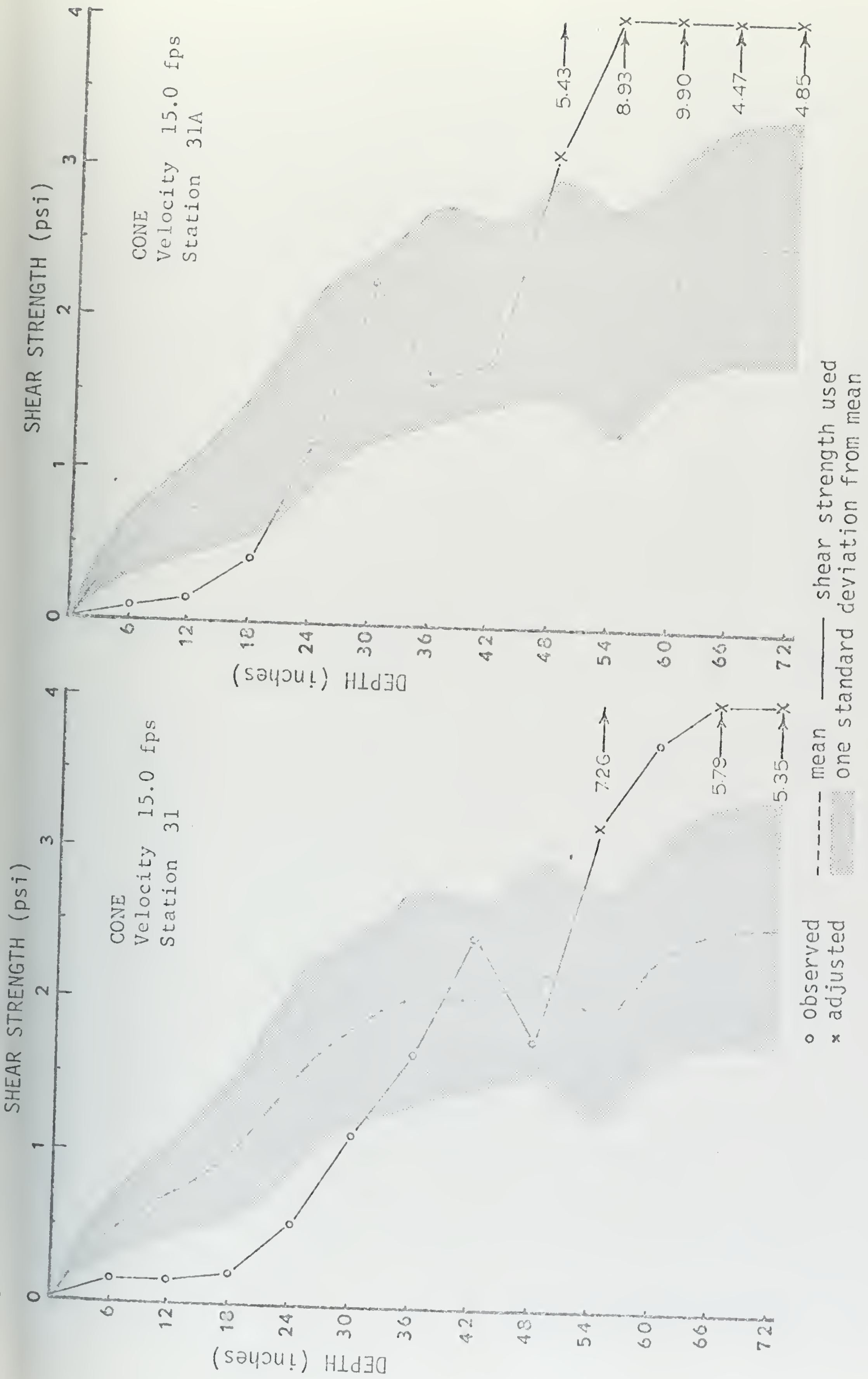

SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 0.0 fps
Station 23B
5.78
4.52
5.30
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 0.0 fps
Station 23C
4.95
4.70
5.70
○ observed
× adjusted
------ mean
——— shear strength used
one standard deviation from mean

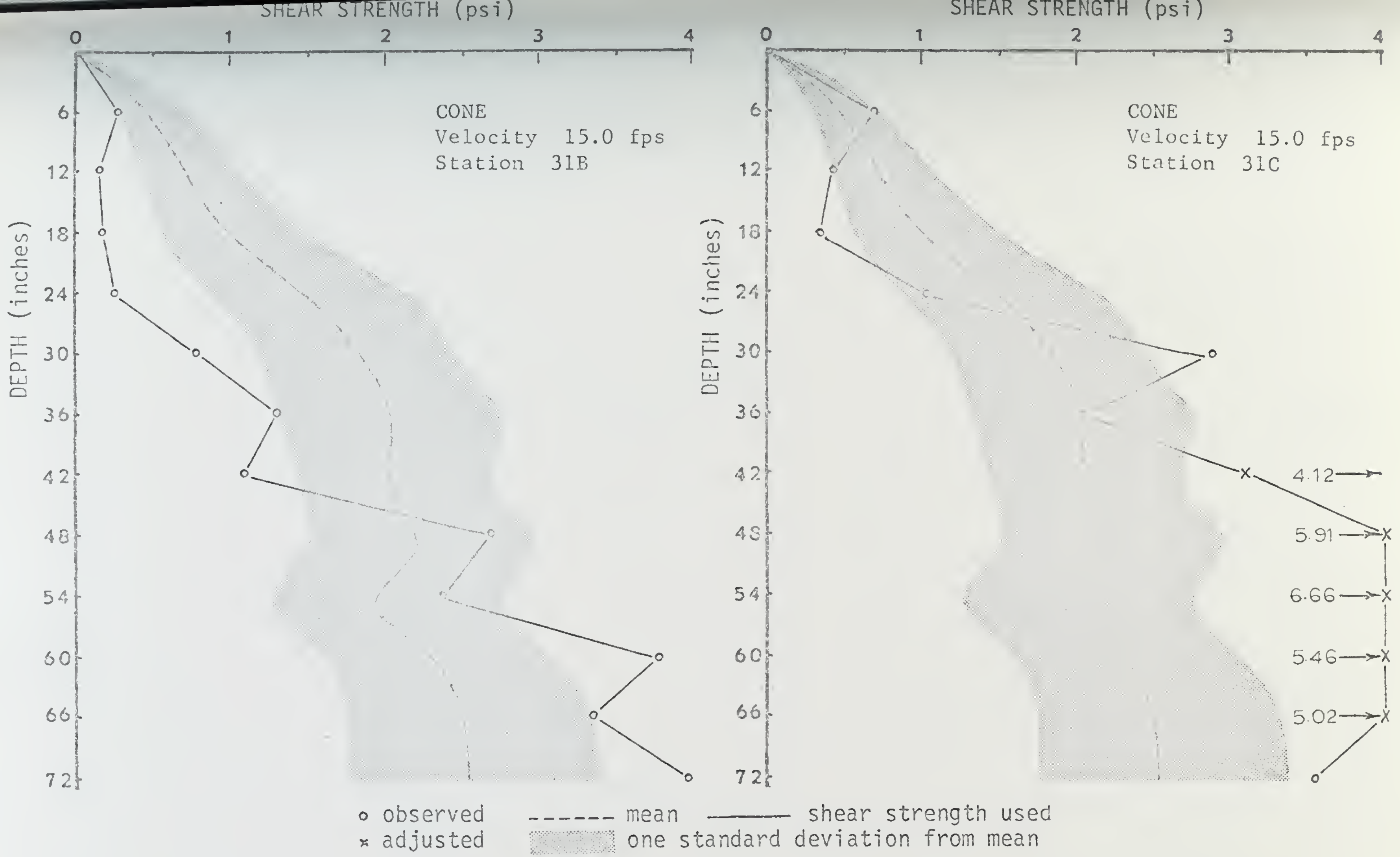

SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 5.0 fps
Station 13
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 5.0 fps
Station 13A
8.60
9.99
5.21
o observed
× adjusted
------ mean
▨ one standard deviation from mean
——— shear strength used

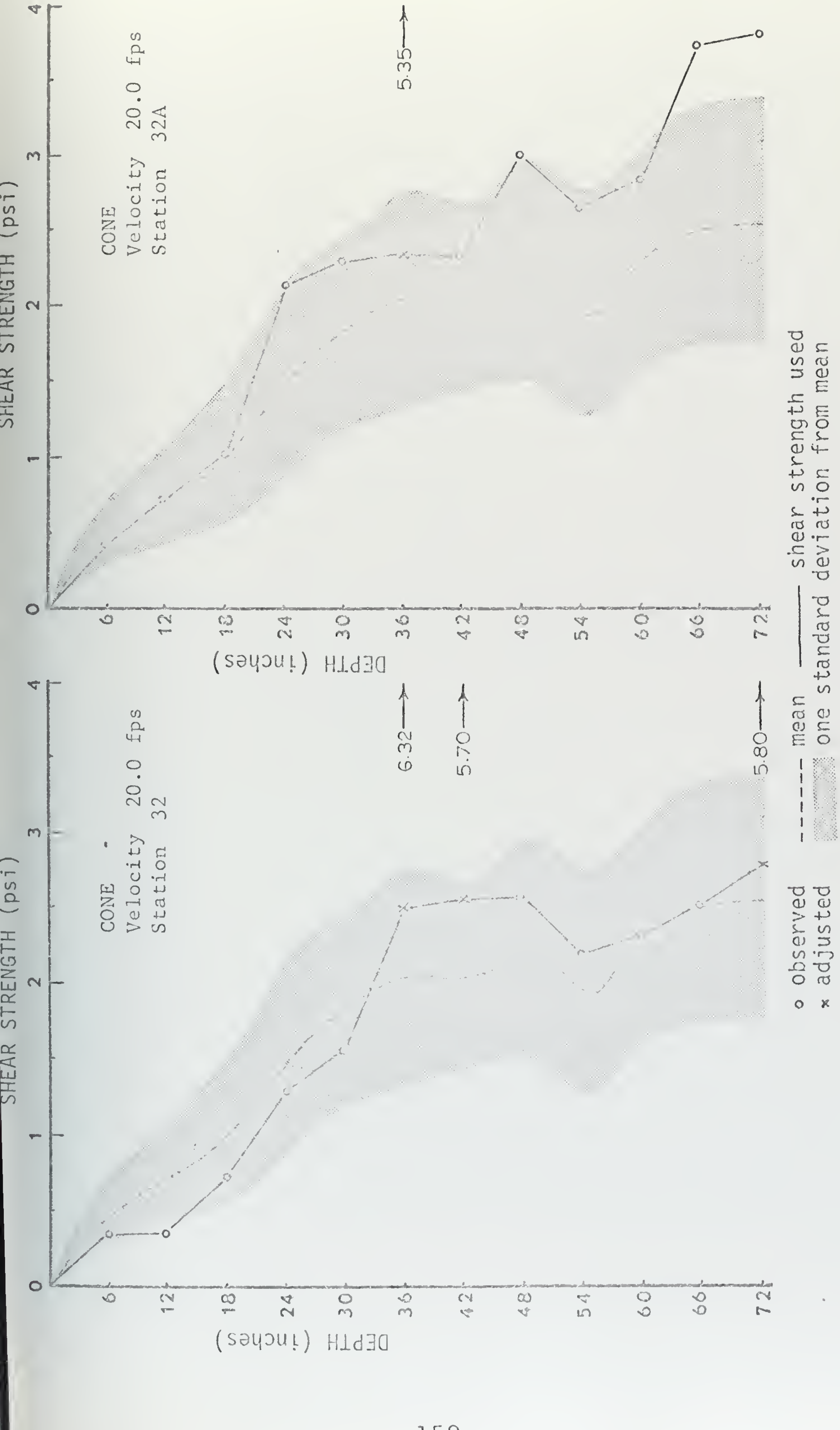

SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 5.0 fps
Station 13B
CONE
Velocity 5.0 fps
Station 13C
o observed
x adjusted
------ mean
▨ one standard deviation from mean
——— shear strength used


SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 10.0 fps
Station 30
7.50
6.30
6.90
4.92
8.70
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 10.0 fps
Station 30A
4.78
5.00
8.46
5.80
6.11
5.45
o observed
× adjusted
------ mean
——— shear strength used
one standard deviation from mean

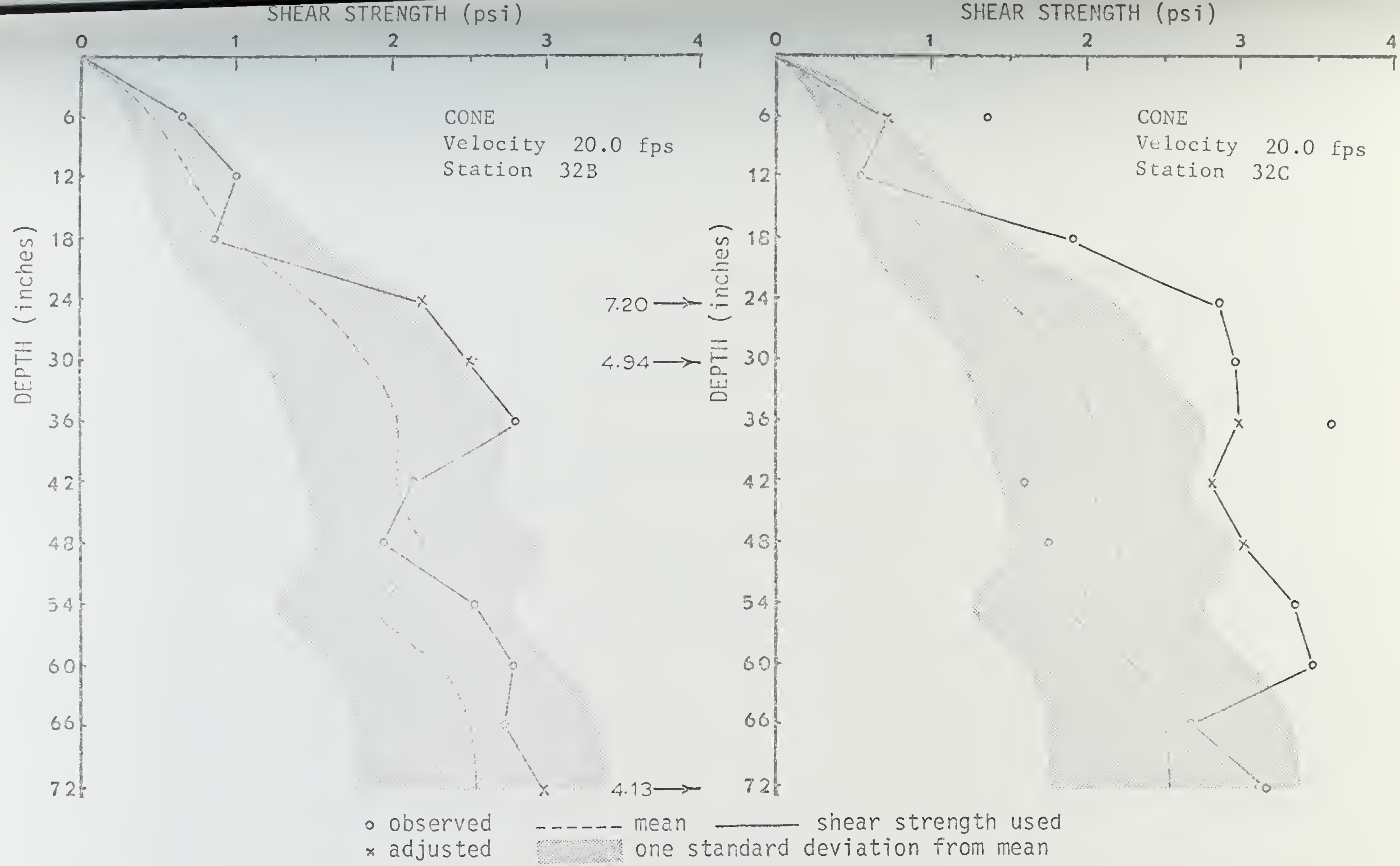

SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 10.0 fps
Station 30B
8.32
9.46
7.64
4.93
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 10.0 fps
Station 30C
4.38
○ observed
× adjusted
------ mean
—— shear strength used
▨ one standard deviation from mean


SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 15.0 fps
Station 31
7.26
5.79
5.35
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 15.0 fps
Station 31A
5.43
8.93
9.90
4.47
4.85
o observed
x adjusted
------- mean
—— shear strength used
one standard deviation from mean


SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 15.0 fps
Station 31B
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 15.0 fps
Station 31C
4.12
5.91
6.66
5.46
5.02
o observed
x adjusted
------ mean
one standard deviation from mean
——— shear strength used



CONE -
Velocity 20.0 fps
Station 32
SHEAR STRENGTH (psi)
DEPTH (inches)
0
1
2
3
4
6
12
18
24
30
36
42
48
54
60
66
72
6.32
5.70
5.80
CONE
Velocity 20.0 fps
Station 32A
SHEAR STRENGTH (psi)
DEPTH (inches)
5.35
o observed
× adjusted
- - - - - mean
▨ one standard deviation from mean
——— shear strength used


SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 20.0 fps
Station 32B
7.20
4.94
4.13
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 20.0 fps
Station 32C
○ observed
× adjusted
------ mean
▨ one standard deviation from mean
—— shear strength used

APPENDIX C: COMPUTATION OF SPHERE PENETRATION

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX      INCREMENT SIZE
C
C BWD     BULK WET DENSITY OF SEDIMENT
C
C BMASS   OBJECT MASS
C
C AMASS() ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( ) PROJECTED AREA FOR SECTION ( )
C
C CNC     BEARING CAPACITY COEFFICIENT
C
C VOL( )  VOLUME OF SECTION ( )
C
C CFOOT   BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX     DEPTH OF PENETRATION
C
C SVOL( ) SUM OF VOLUMES TO SECTION INDICATED
C
C V( )    VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )   WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT      WEIGHT OF OBJECT
C
C G       ACCELERATION OF GRAVITY
C
C SPS     SHEAR STRENGTH OF SEDIMENT
C
C RAD     RADIUS
C
C WDRAG   WORK DONE BY DRAG FORCES
C
C WB( )   WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )   WORK TO SUBMERGE SECTION ( )
```

```
C
C SUMSUB()WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )    KINETIC ENERGY OR BODY AT SECTION( )
C
C
      DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
     20),WB(100),WBSUB(50),US(50),SUMSUB(50),E(100),V(100)
C     RESET DIMENSIONS FOR LARGE OBJECTS
      DATA PI/3.141593/,G/32.1725/,AREA/100*0.0/,VOL/100*0.0/,AMASS/100*
     20.0/,DMASS/100*0.0/,SVOL/100*0.0/,WS/100*0.0/,WB/100*0.0/,WBSUB/50
     3*0.0/,US/50*0.0/,SUMSUB/50*0.0/,E/100*0.0/,V/100*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT SPHERE
      RAD=1.192
      WT=561.
      BWD=87.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C     FOR A SPHERE USE A COEFFICIENT OF DRAG EQUAL TO 0.3
      CD=0.3
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF SPHERE
      Y=DX/2.
      YMAX=2*RAD
      Z=RAD/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
      AREA(1)=PI*(RAD**2-(RAD-Y)**2)
      DO 100 I=2,N
      AREA(I)=PI*(RAD**2-(RAD-(I-1)*DX-Y)**2)
  100 CONTINUE
C
C     FOR THIS ANALYSIS AFTER THE AREA HAS BECOME A MAXIMUM IT WILL BE
C     CONSTANT FOR THE REMAINING PENETRATION THEREFORE SET SUCCEEDING
C     AREAS AS FOLLOWS
```

```
      DO 200 I=N,100
      AREA(I)=AREA(N)
  200 CONTINUE
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVOL=(2./3.)*PI*RAD**3
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
C     PRINT,CVOL,HAFVOL,ERROR
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS AND
C     DISPLACED MASS FROM SECTION TO SECTION
C     APPROXIMATE BY USING ONE HALF ON AN ELIPTICAL FORM. AMASS BECOMES
C     CONSTANT WHEN MAX AREA HAS BEEN REACHED
C
      SUMVOL=0.0
      K=N+1
C     INTEGERS TRUNCATE SO THERE IS AN APPROXIMATION HERE IN THE NUMBER
C     OF ITERATIONS TAKEN
      DO 400 I=2,K
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
      B=(I-1)*DX-Y
      A=RAD**2-(RAD-B)**2
      AS=SQRT(A)
      EE=1-(B**2)/A
      D=SQRT(EE)
C
C     NOW ADDED MASS,DESIGNATE SOME NEW VARIABLES
      SI=ARSIN(D)
      SQRE=SQRT(1-D**2)
C     ADD DISPLACED VOL AT THE SAME TIME
      AMASS(I-1)=BWD*((2./3.)*PI*AS**3*((D-SI*SQRE)/(SI-D*SQRE)))
C
C     SUM THE VOLUMES BEFORE ADDING
C
      SUMVOL=SUMVOL+VOL(I-1)
```

```
C      SUMVOL AT END OF DO LOOP SHOULD EQUAL HAFVOL
C
       AMASS(I-1)=AMASS(I-1)+BWD*SUMVOL
  400  CONTINUE
C
C      CHECK ADDED MASS BY COMPARING LAST INCREMENT TO ONE HALF SPHERE
C
       HAMAS=BWD*(PI*RAD**3)
       ERROR=HAMAS-AMASS(N)
C      PRINT,HAMAS,AMASS(N),ERROR
C
C      AMASS REMAINS THE SAME AFTER MAX AREA
C
       DO 450 I=N.100
       AMASS(I)=AMASS(N)
  450  CONTINUE
C
C      COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
       DMASS(1)=0.0
       DO 500 I=2.N
       DMASS(I)=AMASS(I)-AMASS(I-1)
  500  CONTINUE
C
C      SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C
       CDMASS=DMASS(1)
       DO 550 I=2,N
       CDMASS=CDMASS+DMASS(I)
  550  CONTINUE
C      PRINT,CDMASS,AMASS(N)
C
C
C
C      CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C      PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C      ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
       CT=CFOOT*CNC
       DO 600 I=1,100
       WS(I)=CT*COH*AREA(I)*DX
  600  CONTINUE
C
C
C
C      CALCULATE WORK DONE BY BUOYANCY
C
       GAMMA=BWD*G
       WB(1)=(GAMMA*AREA(1)*DX**2)/2.
       SUMSUB(1)=2.0*WB(1)
```

```
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
      PRINT,CWB
C
C     ACTUAL WORK BY INTEGRATION IS
C
C
      X=N*DX
      AWB=(GAMMA*PI/3.)*(RAD*X**3-X**4/4.)
      PRINT,AWB
C
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) RAD,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
```

```
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
      SLOPE1=SS05/.5
      BINT1=0.0
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE
C                                       CALCULATION
C     FOR THE SPHERE TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE PENETRA
C     TION DEPTH MINUS ONE HALF THE PENETRATION DEPTH UP TO THE MAX RAD
      DEPTH=I*DX-Y-(I*DX-Y)/2.
C     WHEN THE MAX RAD IS REACHED THE DEPTH EQUALS PENETRATION DEPTH
C     MINUS ONE HALF THE RADIUS
      IF((I*DX-Y).GT.RAD) DEPTH=I*DX-Y-RAD/2.
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
```

```
C
      IF(DEPTH.LE..5) GO TO 1
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
```

```
C       SECTION TO COMPUTE THE WORK DONE BY DRAG
C       APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C       FIRST TIME OVER THE SECTION, AS DONE ABOVE
        VAVG=(V(I)+V(I+1))/2.
        IF(I.EQ.1) VAVG=(VO+V(I+1))/2.
        WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
        VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
      2S(I))
        IF (VELOSQ.LE.0.0)GO TO 1000
        V(I+1)=SQRT(VELOSQ)
C
C       CALCULATE E AT NEXT SECTION
        E(I+1)=BMASS*V(I+1)**2/2.
C
C       CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
        EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C       COMPUTE PENETRATION DEPTH
        XXX=I*DX
C
C       PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C       SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C       WORKDONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C       AND DRAG
C
        WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000   CONTINUE
 1000   CONTINUE
 2050   FORMAT(I5)
 2060   FORMAT(' ',I3)
 2100   FORMAT(F5.1,8F5.2)
 2200   FORMAT('1',9X,'SPHERE'//9X,'RADIUS = ',F7.3/9X,'WEIGHT = ',F7.1,'
      2LBS'/9X,'BULK WET DENSITY = ',F5.2,'SLUGS PER CUBIC FOOT'/9X,'DRAG
      3 COEFFICIENT = ',F5.2///)
 2300   FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
      2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500   FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
      2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
      3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
      4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
      5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
      6ORCES'//)
 2600   FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
        STOP
        END
```

```
SPHERE

RADIUS =    1.192
WEIGHT =    561.0 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


 IMPACT VELOCITY EQUALS  0.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
        0.30  0.38  0.78  0.70  1.34  1.63  1.53  1.55


              CONDITIONS AT THE END OF SECTION                              WORK DONE IN SECTION - FOOT POUNDS

     ITERATION PENETRATION     VELOCITY    SHEAR      BODY ENERGY     STATIC     SEDIMENT     BUOYANT    FORM DRAG
      SECTION     FEET          FT/SEC  STRENGTH PSF    FT-LBS        FORCES     INERTIA      FORCES     FORCES

        1         0.05          1.787       1.080       27.832        0.074       0.121       0.020      0.003
        2         0.10          2.482       3.240       53.726        0.653       1.352       0.100      0.051
        3         0.15          2.971       5.400       76.958        1.775       2.653       0.256      0.135
        4         0.20          3.335       7.560       96.945        3.402       3.928       0.486      0.246
        5         0.25          3.605       9.720      113.323        5.496       5.017       0.785      0.375
        6         0.30          3.800      11.880      125.391        8.020       5.801       1.151      0.510
        7         0.35          3.929      14.040      134.579       10.936       6.205       1.580      0.641
        8         0.40          3.999      16.200      139.415       14.206       6.181       2.068      0.759
        9         0.45          4.014      18.360      140.492       17.792       5.711       2.612      0.858
       10         0.50          3.978      20.520      137.949       21.658       4.796       3.209      0.929
       11         0.55          3.890      22.680      131.956       25.764       3.453       3.856      0.969
       12         0.60          3.751      24.840      122.700       30.074       1.710       4.548      0.975
       13         0.65          3.558      27.000      110.373       34.550      -0.398       5.282      0.943
       14         0.70          3.304      29.160       95.171       39.154      -2.829       6.055      0.872
       15         0.75          2.977      31.320       77.286       43.847      -5.539       6.864      0.762
       16         0.80          2.555      33.480       56.906       48.594      -8.480       7.705      0.613
       17         0.85          1.981      35.640       34.208       53.355     -11.607       8.574      0.425
       18         0.90          1.037      37.800        9.370       58.093     -14.867       9.469      0.193
```

```
 SPHERE

RADIUS =    1.192
WEIGHT =    561.0 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


  IMPACT VELOCITY EQUALS  5.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.36  1.04  1.03  1.56  2.41  2.68  2.61  2.16


                    CONDITIONS AT THE END OF SECTION
                                                                  WORK DONE IN SECTION - FOOT POUNDS

      ITERATION PENETRATION      VELOCITY   SHEAR     BODY ENERGY        STATIC      SEDIMENT       BUOYANT     FORM DRAG
       SECTION      FEET          FT/SEC  STRENGTH PSF   FT-LBS          FORCES      INERTIA        FORCES      FORCES

         1          0.05          5.298      1.296      244.746          0.089        1.060          0.020        0.100
         2          0.10          5.534      3.888      266.986          0.784        4.600          0.100        0.325
         3          0.15          5.718      6.480      285.087          2.130        6.989          0.256        0.573
         4          0.20          5.855      9.072      298.890          4.082        8.849          0.486        0.830
         5          0.25          5.946     11.664      308.283          6.595       10.192          0.785        1.084
         6          0.30          5.994     14.256      313.250          9.624       10.983          1.151        1.326
         7          0.35          6.000     16.848      313.858         13.123       11.195          1.580        1.544
         8          0.40          5.965     19.440      310.240         17.047       10.823          2.068        1.730
         9          0.45          5.891     22.032      302.573         21.351        9.876          2.612        1.877
        10          0.50          5.778     24.624      291.060         25.989        8.382          3.209        1.981
        11          0.55          5.626     27.216      275.923         30.917        6.378          3.856        2.036
        12          0.60          5.433     29.808      257.385         36.089        3.908          4.548        2.041
        13          0.65          5.199     32.400      235.673         41.460        1.025          5.282        1.995
        14          0.70          4.920     34.992      211.064         46.984       -2.217          6.055        1.896
        15          0.75          4.589     37.584      183.590         52.617       -5.763          6.864        1.745
        16          0.80          4.198     40.176      153.632         58.313       -9.555          7.705        1.545
        17          0.85          3.730     42.768      121.320         64.026      -13.536          8.574        1.298
        18          0.90          3.156     45.360       85.836         69.712      -17.652          9.469        1.005
        19          0.95          2.403     47.952       50.351         75.325      -21.846         10.385        0.670
        20          1.00          1.175     50.544       12.036         80.821      -26.059         11.320        0.283
```

```
SPHERE

RADIUS =     1.192
WEIGHT =     561.0 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.49  0.77  0.85  2.07  2.43  1.19  1.19  1.77


               CONDITIONS AT THE END OF SECTION                   WORK DONE IN SECTION - FOOT POUNDS

     ITERATION PENETRATION     VELOCITY   SHEAR      BODY ENERGY       STATIC     SEDIMENT       BUOYANT    FORM DRAG
      SECTION        FEET       FT/SEC  STRENGTH PSF    FT-LBS          FORCES     INERTIA        FORCES     FORCES

          1          0.05       10.135      1.764       895.509          0.121       3.878         0.020        0.383
          2          0.10       10.199      5.292       906.896          1.067      14.349         0.100        1.146
          3          0.15       10.216      8.820       909.886          2.899      20.019         0.256        1.885
          4          0.20       10.192     12.348       905.645          5.556      23.669         0.486        2.580
          5          0.25       10.131     15.876       894.873          8.977      25.845         0.785        3.216
          6          0.30       10.036     19.404       878.129         13.099      26.762         1.151        3.782
          7          0.35        9.908     22.932       855.917         17.862      26.553         1.580        4.268
          8          0.40        9.749     26.460       828.697         23.203      25.330         2.068        4.669
          9          0.45        9.560     29.988       796.897         29.061      23.195         2.612        4.980
         10          0.50        9.342     33.516       760.915         35.374      20.250         3.209        5.198
         11          0.55        9.094     37.044       721.115         42.082      16.590         3.856      • 5.323
         12          0.60        8.817     40.572       677.829         49.121      12.311         4.548        5.355
         13          0.65        8.510     44.100       631.362         56.432       7.506         5.282        5.297
         14          0.70        8.170     47.628       581.991         63.951       2.263         6.055        5.151
         15          0.75        7.797     51.156       529.970         71.617      -3.332         6.864        4.921
         16          0.80        7.385     54.684       475.528         79.370      -9.197         7.705        4.613
         17          0.85        6.931     58.212       418.878         87.147     -15.253         8.574        4.231
         18          0.90        6.428     61.740       360.214         94.886     -21.424         9.469        3.782
         19          0.95        5.863     65.268       299.717        102.526     -27.638        10.385        3.273
         20          1.00        5.220     68.796       237.558        110.006     -33.826        11.320        2.709
         21          1.05        4.475     71.568       174.587        116.038     -39.389        12.270        2.102
         22          1.10        3.578     73.584       111.614        120.523     -44.196        13.231        1.465
         23          1.15        2.364     75.600        48.726        124.634     -48.700        14.200        0.803
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IMPACT VELOCITY EQUALS 15.0                                           SPHERE

                                                                       RADIUS =      1.192
SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE       WEIGHT =    561.0 LBS
                                                                       BULK WET DENSITY =   2.72SLUGS PER CUBIC FOOT
      0.30   0.37   0.45   2.44   2.73   2.78   2.86   3.14            DRAG COEFFICIENT =   0.30


                   CONDITIONS AT THE END OF SECTION                           WORK DONE IN SECTION - FOOT POUNDS

        ITERATION PENETRATION      VELOCITY   SHEAR      BODY ENERGY      STATIC     SEDIMENT      BUOYANT     FORM DRAG
         SECTION      FEET          FT/SEC  STRENGTH PSF    FT-LBS         FORCES     INERTIA       FORCES      FORCES

            1          0.05         15.071      1.080     1980.215         0.074       8.576        0.020        0.854
            2          0.10         15.048      3.240     1974.368         0.653      30.629        0.100        2.516
            3          0.15         14.972      5.400     1954.411         1.775      41.899        0.256        4.076
            4          0.20         14.856      7.560     1924.218         3.402      48.844        0.486        5.511
            5          0.25         14.709      9.720     1886.209         5.496      52.972        0.785        6.805
            6          0.30         14.536     11.880     1842.166         8.020      54.970        1.151        7.952
            7          0.35         14.342     14.040     1793.470        10.936      55.280        1.580        8.949
            8          0.40         14.132     16.200     1741.219        14.206      54.230        2.068        9.797
            9          0.45         13.907     18.360     1686.282        17.792      52.080        2.612       10.500
           10          0.50         13.670     20.520     1629.354        21.658      49.048        3.209       11.064
           11          0.55         13.423     22.680     1570.980        25.764      45.309        3.856       11.495
           12          0.60         13.167     24.840     1511.595        30.074      41.012        4.548       11.802
           13          0.65         12.903     27.000     1451.536        34.550      36.284        5.282       11.991
           14          0.70         12.631     29.160     1391.074        39.154      31.233        6.055       12.071
           15          0.75         12.353     31.320     1330.416        43.847      25.947        6.864       12.050
           16          0.80         12.068     33.480     1269.723        48.594      20.508        7.705       11.936
           17          0.85         11.776     35.640     1209.123        53.355      14.984        8.574       11.737
           18          0.90         11.478     37.800     1148.715        58.093       9.435        9.469       11.460
           19          0.95         11.174     39.960     1088.578        62.771       3.916       10.385       11.115
           20          1.00         10.863     42.120     1028.775        67.351      -1.525       11.320       10.707
           21          1.05         10.548     43.452      970.116        70.452      -6.263       12.270       10.249
           22          1.10         10.235     43.956      913.365        71.995     -10.180       13.231        9.755
           23          1.15          9.923     44.460      858.489        73.297     -13.809       14.200        9.237
           24          1.20          9.607     44.964      804.673        74.348     -17.814       16.636        8.695
           25          1.25          9.365     45.801      764.627        75.731     -33.453       17.611        8.206
           26          1.30          9.109     46.809      723.373        77.398     -34.462       18.587        7.780
           27          1.35          8.837     47.817      680.919        79.064     -35.465       19.562        7.343
           28          1.40          8.549     48.825      637.270        80.731     -36.462       20.537        6.892
           29          1.45          8.243     49.833      592.434        82.398     -37.454       21.512        6.429
           30          1.50          7.917     50.841      546.418        84.065     -38.440       22.487        5.954
           31          1.55          7.567     51.849      499.228        85.731     -39.420       23.462        5.466
           32          1.60          7.191     52.857      450.871        87.398     -40.395       24.438        4.966
           33          1.65          6.784     53.948      401.279        89.203     -41.427       25.413        4.453
           34          1.70          6.340     55.100      350.404        91.108     -42.499       26.388        3.927
           35          1.75          5.849     56.252      298.255        93.012     -43.564       27.363        3.387
           36          1.80          5.299     57.404      244.837        94.917     -44.623       28.338        2.834
           37          1.85          4.670     58.556      190.160        96.822     -45.675       29.313        2.266
           38          1.90          3.924     59.708      134.231        98.727     -46.721       30.288        1.684
           39          1.95          2.973     60.860       77.059       100.632     -47.759       31.264        1.085
           40          2.00          1.463     62.012       18.665       102.536     -48.780       32.239        0.449
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 SPHERE

RADIUS =     1.192
WEIGHT =    561.0 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


 IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
        0.40  0.52  1.08  1.51  1.74  1.95  2.11  2.44


                    CONDITIONS AT THE END OF SECTION
                                                                        WORK DONE IN SECTION - FOOT POUNDS
      ITERATION PENETRATION    VELOCITY   SHEAR        BODY ENERGY
       SECTION     FEET         FT/SEC  STRENGTH PSF      FT-LBS          STATIC      SEDIMENT       BUOYANT      FORM DRAG
                                                                          FORCES      INERTIA        FORCES       FORCES

          1        0.05         5.298       1.440       244.736          0.099        1.060         0.020        0.100
          2        0.10         5.533       4.320       266.892          0.871        4.597         0.100        0.325
          3        0.15         5.715       7.200       284.773          2.366        6.973         0.256        0.572
          4        0.20         5.849      10.080       298.171          4.536        8.802         0.486        0.828
          5        0.25         5.933      12.960       306.937          7.328       10.090         0.785        1.081
          6        0.30         5.973      15.840       311.030         10.693       10.795         1.151        1.318
          7        0.35         5.968      18.720       310.501         14.581       10.887         1.580        1.530
          8        0.40         5.919      21.600       305.476         18.941       10.358         2.068        1.707
          9        0.45         5.828      24.480       296.128         23.723        9.218         2.612        1.843
         10        0.50         5.694      27.360       282.664         28.877        7.495         3.209        1.931
         11        0.55         5.516      30.240       265.310         34.352        5.227         3.856        1.968
         12        0.60         5.293      33.120       244.300         40.099        2.463         4.548        1.950
         13        0.65         5.022      36.000       219.866         46.067       -0.743         5.282        1.877
         14        0.70         4.696      38.880       192.239         52.205       -4.332         6.055        1.748
         15        0.75         4.306      41.760       161.641         58.463       -8.244         6.864        1.564
         16        0.80         3.836      44.640       128.285         64.792      -12.417         7.705        1.327
         17        0.85         3.255      47.520        92.373         71.140      -16.791         8.574        1.038
         18        0.90         2.491      50.400        54.100         77.458      -21.303         9.469        0.700
         19        0.95         1.252      53.280        13.656         83.695      -25.890        10.385        0.304
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SPHERE

RADIUS =     1.192
WEIGHT =    561.0 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.69  0.66  0.77  1.39  1.56  2.05  2.44  3.01


                 CONDITIONS AT THE END OF SECTION                      WORK DONE IN SECTION - FOOT POUNDS

ITERATION PENETRATION     VELOCITY    SHEAR     BODY ENERGY      STATIC     SEDIMENT     BUDYANT    FORM DRAG
 SECTION      FEET         FT/SEC  STRENGTH PSF    FT-LBS        FORCES     INERTIA      FORCES     FORCES

    1         0.05        10.134        2.484     895.460         0.171       3.878       0.020      0.383
    2         0.10        10.196        7.452     906.428         1.502      14.333       0.100      1.146
    3         0.15        10.207       12.420     900.317         4.082      19.939       0.256      1.883
    4         0.20        10.172       17.388     902.049         7.824      23.435       0.486      2.572
    5         0.25        10.093       22.356     888.141        12.641      25.335       0.785      3.197
    6         0.30         9.972       27.324     867.029        18.445      25.822       1.151      3.744
    7         0.35         9.811       32.292     839.134        25.152      25.013       1.580      4.199
    8         0.40         9.608       37.260     804.879        32.673      23.008       2.068      4.556
    9         0.45         9.365       42.228     764.678        40.922      19.907       2.612      4.808
   10         0.50         9.081       47.196     718.941        49.813      15.815       3.209      4.950
   11         0.55         8.754       52.164     668.059        59.258      10.837       3.856      4.981
   12         0.60         8.381       57.132     612.405        69.171       5.084       4.548      4.901
   13         0.65         7.959       62.100     552.332        79.465      -1.335       5.282      4.711
   14         0.70         7.483       67.068     488.169        90.053      -8.311       6.055      4.415
   15         0.75         6.943       72.036     420.227       100.849     -15.739       6.864      4.017
   16         0.80         6.325       77.004     348.794       111.766     -23.511       7.705      3.523
   17         0.85         5.607       81.972     274.140       122.717     -31.528       8.574      2.940
   18         0.90         4.748       86.940     196.521       133.615     -39.688       9.469      2.273
   19         0.95         3.650       91.908     116.179       144.374     -47.895      10.385      1.528
   20         1.00         1.956       96.876      33.355       154.906     -56.047      11.320      0.694
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IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.28  0.36  0.91  1.39  1.74  1.57  2.05  2.70


                CONDITIONS AT THE END OF SECTION                     WORK DONE IN SECTION - FOOT POUNDS

ITERATION PENETRATION    VELOCITY   SHEAR     BODY ENERGY      STATIC     SEDIMENT      BUOYANT    FORM DRAG
 SECTION       FEET       FT/SEC  STRENGTH PSF   FT-LBS          FORCES     INERTIA       FORCES     FORCES

    1          0.05       15.071       1.008    1980.220        0.069       8.576        0.020       0.854
    2          0.10       15.049       3.024    1974.415        0.610      30.630        0.100       2.516
    3          0.15       14.973       5.040    1954.567        1.657      41.907        0.256       4.077
    4          0.20       14.857       7.056    1924.576        3.175      48.867        0.486       5.512
    5          0.25       14.711       9.072    1886.881        5.130      53.023        0.785       6.807
    6          0.30       14.540      11.088    1843.275        7.485      55.065        1.151       7.956
    7          0.35       14.349      13.104    1795.148       10.207      55.434        1.580       8.956
    8          0.40       14.142      15.120    1743.602       13.259      54.462        2.068       9.808
    9          0.45       13.921      17.136    1689.506       16.606      52.409        2.612      10.517
   10          0.50       13.688      19.152    1633.552       20.214      49.491        3.209      11.089
   11          0.55       13.446      21.168    1576.286       24.047      45.834        3.856      11.529
   12          0.60       13.196      23.184    1518.137       28.069      41.734        4.548      11.847
   13          0.65       12.938      25.200    1459.440       32.247      37.168        5.282      12.049
   14          0.70       12.674      27.216    1400.457       36.543      32.290        6.055      12.144
   15          0.75       12.404      29.232    1341.390       40.924      27.188        6.864      12.140
   16          0.80       12.128      31.248    1282.397       45.354      21.940        7.705      12.044
   17          0.85       11.847      33.264    1223.598       49.798      16.612        8.574      11.865
   18          0.90       11.560      35.280    1165.086       54.220      11.262        9.469      11.610
   19          0.95       11.268      37.296    1106.934       58.586       5.943       10.385      11.287
   20          1.00       10.970      39.312    1049.200       62.861       0.699       11.320      10.904
   21          1.05       10.670      40.608     992.590       65.840      -3.920       12.270      10.469
   22          1.10       10.371      41.184     937.767       67.455      -7.811       13.231       9.998
   23          1.15       10.073      41.760     884.704       68.846     -11.434       14.200       9.501
   24          1.20        9.772      42.336     832.589       70.002     -15.452       16.636       8.979
   25          1.25        9.547      43.292     794.637       71.583     -31.703       17.611       8.509
   26          1.30        9.308      44.444     755.337       73.488     -32.830       18.587       8.105
   27          1.35        9.054      45.596     714.695       75.393     -33.950       19.562       7.687
   28          1.40        8.784      46.748     672.720       77.298     -35.064       20.537       7.254
   29          1.45        8.497      47.900     629.418       79.202     -36.172       21.512       6.808
   30          1.50        8.190      49.052     584.799       81.107     -37.274       22.487       6.348
   31          1.55        7.862      50.204     538.868       83.012     -38.369       23.462       5.874
   32          1.60        7.509      51.356     491.634       84.917     -39.458       24.438       5.387
   33          1.65        7.101      56.433     439.577       93.312     -43.486       25.413       4.866
   34          1.70        6.603      64.353     380.173      106.408     -49.624       26.388       4.282
   35          1.75        5.996      72.273     313.463      119.503     -55.727       27.363       3.620
   36          1.80        5.241      80.193     239.490      132.599     -61.794       28.338       2.879
   37          1.85        4.261      88.113     158.297      145.695     -67.825       29.313       2.059
   38          1.90        2.832      96.033      69.935      158.790     -73.814       30.288       1.148
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SPHERE

RADIUS =     1.192
WEIGHT =     561.0 LBS
BULK WET DENSITY =   2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =   0.30


 IMPACT VELOCITY EQUALS 20.0


SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.52  1.04  1.74  2.29  2.30  2.69  2.70  2.79


                  CONDITIONS AT THE END OF SECTION                      WORK DONE IN SECTION - FOOT POUNDS

     ITERATION PENETRATION    VELOCITY   SHEAR     BODY ENERGY      STATIC    SEDIMENT     BUOYANT    FORM DRAG
      SECTION       FEET       FT/SEC  STRENGTH PSF   FT-LBS         FORCES    INERTIA      FORCES     FORCES

         1          0.05      20.032      1.872     3498.678        0.129     15.153       0.020       1.513
         2          0.10      19.943      5.616     3467.680        1.132     53.382       0.100       4.431
         3          0.15      19.785      9.360     3412.918        3.076     72.336       0.256       7.139
         4          0.20      19.577     13.104     3341.465        5.896     83.521       0.486       9.597
         5          0.25      19.330     16.848     3257.707        9.526     89.709       0.785      11.786
         6          0.30      19.052     20.592     3164.824       13.901     92.179       1.151      13.698
         7          0.35      18.750     24.336     3065.244       18.955     91.755       1.580      15.334
         8          0.40      18.428     28.080     2960.852       24.623     89.046       2.068      16.702
         9          0.45      18.090     31.824     2853.105       30.840     84.527       2.612      17.810
        10          0.50      17.738     35.568     2743.143       37.540     78.585       3.209      18.674
        11          0.55      17.374     39.312     2631.832       44.658     71.532       3.856      19.306
        12          0.60      17.001     43.056     2519.846       52.129     63.626       4.548      19.723
        13          0.65      16.618     46.800     2407.689       59.887     55.084       5.282      19.939
        14          0.70      16.227     50.544     2295.748       67.866     46.089       6.055      19.972
        15          0.75      15.828     54.288     2184.309       76.002     36.788       6.864      19.835
        16          0.80      15.422     58.032     2073.572       84.229     27.308       7.705      19.545
        17          0.85      15.008     61.776     1963.689       92.482     17.762       8.574      19.115
        18          0.90      14.585     65.520     1854.769      100.695      8.247       9.469      18.559
        19          0.95      14.155     69.264     1746.887      108.803     -1.150      10.385      17.892
        20          1.00      13.716     73.008     1640.103      116.741    -10.354      11.320      17.127
        21          1.05      13.266     76.752     1534.458      124.443    -19.296      12.270      16.276
        22          1.10      12.807     80.496     1429.988      131.844    -27.908      13.231      15.353
        23          1.15      12.336     84.240     1326.726      138.878    -36.136      14.200      14.369
        24          1.20      11.848     87.984     1223.921      145.481    -44.597      16.636      13.334
        25          1.25      11.425     94.199     1138.014      155.757    -71.763      17.611      12.349
        26          1.30      10.950    101.687     1045.341      168.138    -77.416      18.587      11.414
        27          1.35      10.416    109.175      945.938      180.520    -83.037      19.562      10.408
        28          1.40       9.815    116.663      839.844      192.901    -88.627      20.537       9.331
        29          1.45       9.132    124.151      727.098      205.282    -94.184      21.512       8.185
        30          1.50       8.349    131.639      607.737      217.664    -99.709      22.487       6.968
        31          1.55       7.434    139.127      481.801      230.045   -105.202      23.462       5.680
        32          1.60       6.330    146.615      349.329      242.426   -110.662      24.438       4.320
        33          1.65       4.896    155.606      209.013      257.293   -117.215      25.413       2.874
        34          1.70       2.622    165.686       59.947      273.960   -124.523      26.388       1.290
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 SPHERE

RADIUS =     1.192
WEIGHT =   561.0 LBS
BULK WET DENSITY =   2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =   0.30


 IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.71  0.71  1.45  1.74  2.09  2.21  2.38  2.30


                 CONDITIONS AT THE END OF SECTION
                                                                 WORK DONE IN SECTION - FOOT POUNDS

     ITERATICN PENETRATION     VELOCITY   SHEAR     BODY ENERGY       STATIC      SEDIMENT       BUOYANT     FORM DRAG
      SECTION      FEET         FT/SEC  STRENGTH PSF   FT-LBS         FORCES      INERTIA        FORCES      FORCES

         1         0.05        20.032       2.556    3498.631          0.175       15.152         0.020         1.513
         2         0.10        19.942       7.668    3467.232          1.546       53.367         0.100         4.431
         3         0.15        19.781      12.760    3411.424          4.200       72.259         0.256         7.137
         4         0.20        19.567      17.892    3338.043          8.051       83.299         0.486         9.590
         5         0.25        19.311      23.004    3251.307         13.007       89.224         0.785        11.768
         6         0.30        19.021      28.116    3154.273         18.980       91.286         1.151        13.662
         7         0.35        18.701      33.228    3049.293         25.881       90.292         1.580        15.269
         8         0.40        18.358      38.340    2938.217         33.620       86.839         2.068        16.595
         9         0.45        17.993      43.452    2822.488         42.109       81.402         2.612        17.647
        10         0.50        17.608      48.564    2703.256         51.257       74.371         3.209        18.438
        11         0.55        17.207      53.676    2581.424         60.976       66.068         3.856        18.981
        12         0.60        16.790      58.788    2457.689         71.176       56.761         4.548        19.291
        13         0.65        16.357      63.900    2332.611         81.768       46.687         5.282        19.383
        14         0.70        15.909      69.012    2206.623         92.663       36.046         6.055        19.274
        15         0.75        15.446      74.124    2080.057        103.772       25.001         6.864        18.978
        16         0.80        14.967      79.236    1953.178        115.005       13.709         7.705        18.512
        17         0.85        14.473      84.348    1826.188        126.274        2.299         8.574        17.892
        18         0.90        13.961      89.460    1699.256        137.488       -9.107         9.469        17.133
        19         0.95        13.430      94.572    1572.511        148.558      -20.401        10.385        16.251
        20         1.00        12.879      99.684    1446.068        159.396      -31.486        11.320        15.261
        21         1.05        12.315     102.240    1322.361        165.769      -40.473        12.270        14.191
        22         1.10        11.750     102.240    1203.691        167.458      -47.048        13.231        13.080
        23         1.15        11.181     102.240    1089.920        168.553      -52.885        14.200        11.953
        24         1.20        10.603     102.240     980.122        169.053      -58.661        16.636        10.818
        25         1.25        10.094     102.240     888.379        169.053      -76.638        17.611         9.766
        26         1.30         9.559     102.240     796.628        169.053      -76.645        18.587         8.806
        27         1.35         8.991     102.240     704.869        169.053      -76.652        19.562         7.846
        28         1.40         8.386     102.240     613.102        169.053      -76.659        20.537         6.885
        29         1.45         7.733     102.240     521.327        169.053      -76.665        21.512         5.924
        30         1.50         7.019     102.240     429.545        169.053      -76.671        22.487         4.962
        31         1.55         6.224     102.240     337.757        169.053      -76.677        23.462         3.999
        32         1.60         5.311     102.240     245.963        169.053      -76.681        24.438         3.034
        33         1.65         4.129     108.420     148.615        179.272      -81.320        25.413         2.032
        34         1.70         2.188     119.076      41.748        196.891      -89.273        26.388         0.911
```

APPENDIX D: COMPUTATION OF A CYLINDER PENETRATING HORIZONTALLY

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A CYLINDER ON ITS SIDE
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX       INCREMENT SIZE
C
C BWD      BULK WET DENSITY OF SEDIMENT
C
C BMASS    OBJECT MASS
C
C AMASS()  ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( )  PROJECTED AREA FOR SECTION ( )
C
C CNC      BEARING CAPACITY COEFFICIENT
C
C VOL( )   VOLUME OF SECTION ( )
C
C CFOOT    BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX      DEPTH OF PENETRATION
C
C SVOL( )  SUM OF VOLUMES TO SECTION INDICATED
C
C V( )     VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )    WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT       WEIGHT OF OBJECT
C
C G        ACCELERATION OF GRAVITY
C
C SPS      SHEAR STRENGTH OF SEDIMENT
C
C RAD      RADIUS
C
C DIM      LENGTH OF CYLINDER
C
C WDRAG    WORK DONE BY DRAG FORCES
C
C WB( )    WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
```

```
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )   WORK TO SUBMERGE SECTION ( )
C
C SUMSUB()WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )    KINETIC ENERGY OF BODY AT SECTION( )
C
C
      DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
     20),WB(100),WBSUB(100),US(100),SUMSUB(100),E(100),V(100)
      DATA PI/3.141593/,G/32.1725/,AREA/100*0.0/,VOL/100*0.0/,AMASS/100*
     20.0/,DMASS/100*0.0/,SVOL/100*0.0/,WS/100*0.0/,WB/100*0.0/,WBSUB/10
     30*0.0/,US/100*0.0/,SUMSUB/100*0.0/,E/100*0.0/,V/100*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT HORIZONTAL CYLINDER
      RAD=.94791
      WT=540.75
      DIM=33.834/12.
      BWD=37.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C
C     FOR A CYLINDER USE A COEFFICIENT OF DRAG EQUAL TO 0.68
      CD=0.68
C
C
C     SET INCREMENT
      DX=.05
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF SPHERE
      Y=DX/2.
      YMAX=2*RAD
      Z=RAD/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
      DIM2=2.*(RAD**2-(RAD-Y)**2)
      AREA(1)=DIM*DIM2
      DO 100 I=2,N
      AREA(I)=DIM*2.*SQRT(RAD**2-(RAD-(I-1)*DX-Y)**2)
```

```
C     PRINT,AREA(I)
  100 CONTINUE
C
C     FOR THIS ANALYSIS AFTER THE AREA HAS BECOME A MAXIMUM IT WILL BE
C     CONSTANT FOR THE REMAINING PENETRATION THEREFORE SET SUCCEEDING
C     AREAS AS FOLLOWS
      DO 200 I=N,100
      AREA(I)=AREA(N)
C     PRINT,AREA(I)
  200 CONTINUE
C
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVOL=PI*RAD**2*DIM/2.
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
C     PRINT,CVOL,HAFVOL,ERROR
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE BY USING ONE HALF OF A PROLATE ELLIPSOID.
C     AMASS BECOMES CONSTANT WHEN THE MAXIMUM AREA HAS BEEN REACHED.
C
      SUMVOL=0.0
      K=N+1
      DO 400 I=2,K
C     CHANGE THE PROJECTED RECTANGULAR AREA INTO A ELLIPSE OF THE
C     EQUIVALENT AREA KEEPING THE RATIO OF MAXIMUM AND MINIMUM
C     DIMENSIONS THE SAME FOR THE RECTANGLE AND ELLIPSE
      AA=DIM
      BB=2.*SQRT(RAD**2-(RAD-(I-1)*DX-Y)**2)
C     THE ELLIPSE DIMENSIONS ARE
      A=SQRT(DIM**2/PI)
      R=AA/BB
      B=A/R
```

```
      REA=PI*A*B
C     PRINT,A,B,REA
C     NOW FORM THE APPROXIMATE PROLATE ELLIPSOID USING DIMENSIONS OF
C     EQUIVALENT ELLIPSE AND PENETRATION DEPTH
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
C     EK IS A VARIABLE OF HYPERBOLIC FORM FOR THE ADDED MASS EQUATION
C     APPROXIMATE EK BY A SERIES OF STRAIGHT LINES
      IF(R.LE.1.0) GO TO 400
      IF((R.LE.1.50).AND.(R.GT.1.00)) GO TO 12
      IF((R.LE.2.00).AND.(R.GT.1.50)) GO TO 13
      IF((R.LE.2.51).AND.(R.GT.2.00)) GO TO 14
      IF((R.LE.2.99).AND.(R.GT.2.51)) GO TO 15
      IF((R.LE.3.99).AND.(R.GT.2.99)) GO TO 16
      IF((R.LE.4.99).AND.(R.GT.3.99)) GO TO 17
      IF((R.LE.6.01).AND.(R.GT.4.99)) GO TO 18
      IF((R.LE.6.97).AND.(R.GT.6.01)) GO TO 19
      IF(R.GT.6.97) GO TO 20
   12 EK=.2420*R+.2580
      GO TO 21
   13 EK=.1620*R+.3780
      GO TO 21
   14 EK=.1196*R+.4628
      GO TO 21
   15 EK=.0833*R+.5629
      GO TO 21
   16 EK=.0570*R+.6326
      GO TO 21
   17 EK=.0350*R+.7204
      GO TO 21
   18 EK=.0226*R+.7825
      GO TO 21
   19 EK=.0156*R+.8241
      GO TO 21
   20 EK=.0090*R+.8703
      GO TO 21
C
C     NOW ADDED MASS,DESIGNATE SOME NEW VARIABLES
C     ADD DISPLACED VOL AT THE SAME TIME
   21 AMASS(I-1)=EK*(2./3.)*BWD*PI*A*B**2
C
C     SUM THE VOLUMES BEFORE ADDING
C
      SUMVOL=SUMVOL+VOL(I-1)
C     SUMVOL AT END OF DO LOOP SHOULD EQUAL HAFVOL
      AMASS(I-1)=AMASS(I-1)+BWD*SUMVOL
C     PRINT,AA,BB,A,B,R,EK,AMASS(I-1)
  400 CONTINUE
C
```

```
C     CHECK ADDED MASS BY COMPARING LAST INCREMENT TO ONE HALF ELLIPSOID
C
      HAMAS=BWD*(EK*(2./3.)*PI*A*B**2+PI*RAD**2*DIM/2.)
      ERROR=HAMAS-AMASS(N)
      PRINT,HAMAS,AMASS(N),ERROR
C
C
C     AMASS REMAINS THE SAME AFTER MAX AREA
C
      DO 450 I=N,100
      AMASS(I)=AMASS(N)
  450 CONTINUE
C
C
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
  500 CONTINUE
C
C     SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C
      CDMASS=DMASS(1)
      DO 550 I=2,N
      CDMASS=CDMASS+DMASS(I)
  550 CONTINUE
      PRINT,CDMASS,AMASS(N)
C
C
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,100
      WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY
C
      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
```

```
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
C     PRINT,WB(I)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION.
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
C     PRINT,WB(I)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
C     PRINT,CWB
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) RAD,DIM,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
```

```
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
      SLOPE1=SS05/.5
      BINT1=0.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE CYLINDER TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE
C     PENETRATION DEPTH MINUS ONE HALF THE PENETRATION DEPTH
      DEPTH=I*DX-Y-(I*DX-Y)/2.
C     WHEN THE MAX RAD IS REACHED THE DEPTH EQUALS PENETRATION DEPTH
C     MINUS ONE HALF THE RADIUS
      IF((I*DX-Y).GT.RAD) DEPTH=I*DX-Y-RAD/2.
C
```

```
C       CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
        DEPTHI=DEPTH*12.
C
C       SELECT PROPER DEPTH
        IF(DEPTH.LE..5) GO TO 1
        IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
        IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
        IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
        IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
        IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
        IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
        IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C       FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C       AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
        IF(DEPTH.GT.4.0) GO TO 9
C
C       FORMULAS FOR SHEAR STRENGTH FOLLOW
C       LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
    1   SSS=SLOPE1*DEPTH
        GO TO 10
    2   SSS=SLOPE2*DEPTH+BINT2
        GO TO 10
    3   SSS=SLOPE3*DEPTH+BINT3
        GO TO 10
    4   SSS=SLOPE4*DEPTH+BINT4
        GO TO 10
    5   SSS=SLOPE5*DEPTH+BINT5
        GO TO 10
    6   SSS=SLOPE6*DEPTH+BINT6
        GO TO 10
    7   SSS=SLOPE7*DEPTH+BINT7
        GO TO 10
    8   SSS=SLOPE8*DEPTH+BINT8
        GO TO 10
    9   SSS=(SS30+SS305+SS40)/3.
C
C       SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10   SPS=SSS*144.
C       CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C       ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
        CT=CFOOT*CNC
        WS(I)=CT*SPS*AREA(I)*DX
        AMASS1=(AMASS(I)*V(I)**2/2.)
        VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
        IF (VELOSQ.LE.0.0)GO TO 1000
```

```
      V(I+1)=SQRT(VELOSQ)
C
C
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
C     APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C     FIRST TIME OVER THE SECTION, AS DONE ABOVE
      VAVG=(V(I)+V(I+1))/2.
      IF(I.EQ.1) VAVG=(V0+V(I+1))/2.
      WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
     2S(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C     CALCULATE E AT NEXT SECTION
      E(I+1)=BMASS*V(I+1)**2/2.
C
C     CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
      EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C     COMPUTE PENETRATION DEPTH
      XXX=I*DX
C
C     PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C     SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C     WORKDONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C     AND DRAG
C
      WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000 CONTINUE
 1000 CONTINUE
 2050 FORMAT(I5)
 2060 FORMAT(' ',I3)
 2100 FORMAT(F5.1,8F5.2)
 2200 FORMAT('1',60X,'CYLINDER'//9X,'RADIUS = ',F7.3/9X,'LENGTH =',F7.3,
     2' FEET'/9X,'WEIGHT = ',F7.1,' LBS'/9X,'BULK WET DENSITY = ',F5.2,'
     3 SLUGS PER CUBIC FOOT'/9X,'DRAG COEFFICIENT = ',F5.2///)
 2300 FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1//10X,'SEDIMENT SHEAR
     2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500 FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
     2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
     3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
     4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
     5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
     6ORCES'//)
 2600 FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
      STOP
```

```
IMPACT VELOCITY EQUALS  0.0
                                                                                     CYLINDER
SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE  RADIUS =    0.948
                                                                  LENGTH =  2.819 FEET
      0.42  1.08  1.48  1.57  2.44  2.72  2.69  2.93              WEIGHT =    540.8 LBS
                                                                  BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
                                                                  DRAG COEFFICIENT =  0.68
                CONDITIONS AT THE END OF SECTION                      WORK DONE IN SECTION - FOOT POUNDS

    ITERATION PENETRATION     VELOCITY   SHEAR       BODY ENERGY      STATIC     SEDIMENT     BUOYANT    FORM DRAG
     SECTION      FEET         FT/SEC  STRENGTH PSF    FT-LBS         FORCES     INERTIA      FORCES     FORCES

        1         0.05         1.719      1.512       24.823          0.148       2.029       0.029       0.009
        2         0.10         2.253      4.536       42.655          3.502       5.037       0.285       0.381
        3         0.15         2.558      7.560       54.977          7.431       5.769       0.803       0.713
        4         0.20         2.720     10.584       62.196         12.135       5.251       1.431       1.002
        5         0.25         2.764     13.608       64.201         17.432       4.245       2.147       1.209
        6         0.30         2.703     16.632       61.391         23.199       2.404       2.936       1.309
        7         0.35         2.538     19.656       54.132         29.342      -0.120       3.787       1.288
        8         0.40         2.254     22.680       42.694         35.784      -3.139       4.693       1.138
        9         0.45         1.806     25.704       27.406         42.459      -6.634       5.645       0.856
       10         0.50         1.011     28.728        8.591         49.307     -10.522       6.638       0.429


IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.51  0.75  1.08  1.88  2.04  1.96  2.38  2.70


                CONDITIONS AT THE END OF SECTION                      WORK DONE IN SECTION - FOOT POUNDS

    ITERATION PENETRATION     VELOCITY   SHEAR       BODY ENERGY      STATIC     SEDIMENT     BUOYANT    FORM DRAG
     SECTION      FEET         FT/SEC  STRENGTH PSF    FT-LBS         FORCES     INERTIA      FORCES     FORCES

        1         0.05         5.102      1.836      218.740          0.179      17.876       0.029       0.311
        2         0.10         5.169      5.508      224.576          4.253      14.112       0.285       2.550
        3         0.15         5.174      9.180      224.939          9.023      13.551       0.803       3.296
        4         0.20         5.127     12.852      220.922         14.735      11.073       1.431       3.816
        5         0.25         5.017     16.524      211.516         21.167       8.992       2.147       4.137
        6         0.30         4.846     20.196      197.349         28.170       5.839       2.936       4.260
        7         0.35         4.613     23.868      178.853         35.630       1.922       3.787       4.195
        8         0.40         4.311     27.540      156.157         43.452      -2.358       4.693       3.947
        9         0.45         3.927     31.212      129.592         51.557      -7.120       5.645       3.521
       10         0.50         3.440     34.884       99.472         59.873     -12.281       6.638       2.927
       11         0.55         2.804     38.556       66.092         68.336     -17.759       7.667       2.173
       12         0.60         1.881     42.228       29.734         76.886     -23.474       8.726       1.258
```

```
                                                      CYLINDER
RADIUS =    0.948
LENGTH =   2.819 FEET
WEIGHT =    540.8 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.68


  IMPACT VELOCITY EQUALS 10.0


 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

       0.26  0.68  1.24  2.04  2.44  2.38  2.33  2.75


                   CONDITIONS AT THE END OF SECTION                   WORK DONE IN SECTION - FOOT POUNDS

         ITERATION PENETRATION    VELOCITY   SHEAR      BODY ENERGY     STATIC     SEDIMENT     BUOYANT    FORM DRAG
          SECTION      FEET        FT/SEC  STRENGTH PSF    FT-LBS       FORCES     INERTIA      FORCES     FORCES

             1         0.05         9.761      0.936      800.685       0.091     65.433       0.029       1.190
             2         0.10         9.598      2.808      774.137       2.168     42.072       0.285       9.060
             3         0.15         9.420      4.680      745.666       4.600     38.963       0.803      11.143
             4         0.20         9.248      6.552      718.744       7.512     32.483       1.431      12.532
             5         0.25         9.058      8.424      689.585      10.791     29.786       2.147      13.472
             6         0.30         8.858     10.296      659.434      14.361     25.835       2.936      14.056
             7         0.35         8.650     12.168      628.845      18.164     21.306       3.787      14.369
             8         0.40         8.433     14.040      597.275      22.152     17.306       4.693      14.456
             9         0.45         8.198     15.912      564.857      26.294     13.180       5.645      14.346
            10         0.50         7.954     17.704      531.703      30.524      8.963       6.638      14.066
            11         0.55         7.697     19.656      497.909      34.838      4.689       7.667      13.638
            12         0.60         7.427     21.528      463.555      39.197      0.386       8.726      13.082
            13         0.65         7.142     23.400      429.710      43.570     -3.915       9.812      12.414
            14         0.70         6.842     25.272      393.435      47.930     -8.188      10.921      11.649
            15         0.75         6.525     27.144      357.782      52.249    -12.408      12.047      10.801
            16         0.80         6.188     29.016      321.600      56.500    -16.553      13.189       9.883
            17         0.85         5.929     30.888      285.580      60.655    -20.646      14.343       8.905
            18         0.90         5.444     32.760      249.072      64.686    -24.526      15.504       7.879
            19         0.95         5.016     34.632      211.436      68.566    -29.166      18.421       6.802
            20         1.00         4.570     37.566      175.499      74.375    -36.655      19.589       5.713
            21         1.05         3.987     43.614      133.578      86.349    -42.700      20.757       4.553
            22         1.10         3.195     49.662       85.813      98.323    -48.654      21.924       3.209
            23         1.15         1.961     55.710       32.306     110.297    -54.501      23.092       1.656
```

```
                                                 CYLINDER
RADIUS =     0.948
LENGTH =   2.819 FEET
WEIGHT =    540.8 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.68


  IMPACT VELOCITY EQUALS 15.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.29   0.52   0.62   0.90   1.30   2.16   1.74   1.76


                   CONDITIONS AT THE END OF SECTION                   WORK DONE IN SECTION - FOOT POUNDS

      ITERATION PENETRATION     VELOCITY   SHEAR      BODY ENERGY      STATIC     SEDIMENT      BUOYANT    FORM DRAG
       SECTION      FEET         FT/SEC  STRENGTH PSF    FT-LBS        FORCES     INERTIA       FORCES     FORCES

          1          0.05        14.514       1.044     1770.448       0.102     144.684       0.029        2.654
          2          0.10        14.166       3.132     1686.849       2.418      88.046       0.285       19.889
          3          0.15        13.817       5.220     1604.277       5.131      79.546       0.803       24.129
          4          0.20        13.492       7.308     1529.904       8.379      64.781       1.431       26.821
          5          0.25        13.160       9.396     1455.385      12.036      58.816       2.147       28.557
          6          0.30        12.829      11.484     1383.054      16.018      50.839       2.936       29.575
          7          0.35        12.503      13.572     1313.741      20.260      42.226       3.787       30.0[illegible]
          8          0.40        12.176      15.660     1245.995      24.709      35.204       4.693       30.180
          9          0.45        11.849      17.749     1179.795      29.317      28.331       5.645       29.946
         10          0.50        11.519      19.836     1115.095      34.046      21.617       6.638       29.437
         11          0.55        11.187      21.924     1051.831      38.858      15.074       7.667       28.703
         12          0.60        10.853      24.012      989.929      43.719       8.711       8.726       27.782
         13          0.65        10.516      26.100      929.314      48.597       2.538       9.812       26.705
         14          0.70        10.174      28.188      869.910      53.460      -3.438      10.921       25.498
         15          0.75         9.827      30.276      811.645      58.278      -9.206      12.047       24.184
         16          0.80         9.475      32.364      754.452      63.019     -14.760      13.189       22.781
         17          0.85         9.116      34.452      698.396      67.653     -20.213      14.343       21.310
         18          0.90         8.749      36.540      643.204      72.150     -25.209      15.504       19.784
         19          0.95         8.365      38.628      588.007      76.477     -30.866      18.421       18.201
         20          1.00         8.034      41.829      542.390      82.815     -46.465      19.589       16.715
         21          1.05         7.664      45.141      493.638      89.372     -49.658      20.757       15.318
         22          1.10         7.251      48.453      441.797      95.929     -52.804      21.924       13.828
         23          1.15         6.785      51.765      385.913     102.487     -55.904      23.092       12.247
         24          1.20         6.257      55.077      329.030     109.044     -58.959      24.259       10.575
         25          1.25         5.649      58.389      268.193     115.601     -61.968      25.427        8.814
         26          1.30         4.932      61.701      204.446     122.158     -64.932      26.595        6.962
         27          1.35         4.050      65.013      137.835     128.716     -67.849      27.762        5.018
         28          1.40         2.853      68.325       68.414     135.273     -70.711      28.930        2.966
```

```
                                                  CYLINDER
      RADIUS =    0.948
      LENGTH =  2.819 FEET
      WEIGHT =    540.8 LBS
      BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
      DRAG COEFFICIENT =  0.68


        IMPACT VELOCITY EQUALS 20.0

       SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

            0.68  0.73  1.74  2.30  2.45  2.60  2.58  2.90


                    CONDITIONS AT THE END OF SECTION                       WORK DONE IN SECTION - FOOT POUNDS

           ITERATION PENETRATION      VELOCITY   SHEAR      BODY ENERGY       STATIC     SEDIMENT       BUOYANT    FORM DRAG
            SECTION       FEET        FT/SEC  STRENGTH PSF     FT-LBS         FORCES     INERTIA        FORCES     FORCES

               1          0.05        19.293       2.448     3127.998         0.239      255.626         0.029       4.705
               2          0.10        18.774       7.344     2962.121         5.670      151.921         0.285      35.034
               3          0.15        18.250      12.240     2799.098        12.031      134.984         0.803      42.237
               4          0.20        17.761      17.136     2651.059        19.647      107.355         1.431      46.639
               5          0.25        17.259      22.032     2503.344        28.223       95.071         2.147      49.304
               6          0.30        16.757      26.928     2359.854        37.560       79.358         2.936      50.669
               7          0.35        16.260      31.824     2221.654        47.506       62.639         3.787      51.100
               8          0.40        15.758      36.720     2086.797        57.936       48.667         4.693      50.798
               9          0.45        15.251      41.616     1954.582        68.742       34.981         5.645      49.887
              10          0.50        14.737      46.512     1825.073        79.831       21.599         6.638      48.480
              11          0.55        14.215      51.408     1698.117        91.115        8.547         7.667      46.665
              12          0.60        13.684      56.304     1573.555       102.514       -4.155         8.726      44.513
              13          0.65        13.141      61.200     1451.228       113.952      -16.483         9.812      42.082
              14          0.70        12.585      66.036     1330.983       125.355      -28.418        10.921      39.422
              15          0.75        12.012      70.992     1212.677       136.651      -39.932        12.047      36.575
              16          0.80        11.421      75.888     1096.184       147.769      -51.006        13.189      33.578
              17          0.85        10.807      80.784      981.556       158.636      -61.779        14.343      30.466
              18          0.90        10.165      85.680      868.384       169.180      -71.743        15.504      27.268
              19          0.95         9.483      90.576      755.782       179.326      -82.104        18.421      23.996
              20          1.00         8.816      97.935      653.104       193.896     -104.586        19.589      20.816
              21          1.05         8.095      98.655      550.646       195.321     -104.362        20.757      17.777
              22          1.10         7.305      99.375      448.407       196.747     -104.139        21.924      14.743
              23          1.15         6.420     100.095      346.385       198.172     -103.918        23.092.     11.713
              24          1.20         5.395     100.815      244.581       199.598     -103.697        24.259       8.681
              25          1.25         4.125     101.535      142.998       201.023     -103.470        25.427       5.639
              26          1.30         2.227     102.255       41.679       202.449     -103.202        26.595       2.515
```

```
                                        CYLINDER
RADIUS =    0.948
LENGTH =  2.819 FEET
WEIGHT =    540.8 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.68


 IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
     0.74  1.09  1.45  1.22  1.43  1.74  1.30  1.50


           CONDITIONS AT THE END OF SECTION
                                                                      WORK DONE IN SECTION - FOOT POUNDS
  ITERATION PENETRATION   VELOCITY   SHEAR        BODY ENERGY
   SECTION      FEET       FT/SEC  STRENGTH PSF      FT-LBS        STATIC     SEDIMENT     BUOYANT     FORM DRAG
                                                                   FORCES     INERTIA      FORCES      FORCES

      1         0.05      19.293       2.664     3127.979        0.260     255.624       0.029        4.705
      2         0.10      18.773       7.992     2961.688        6.170     151.837       0.285       35.031
      3         0.15      18.246      13.320     2797.852       13.093     134.746       0.803       42.225
      4         0.20      17.753      18.648     2648.566       21.380     106.900       1.431       46.607
      5         0.25      17.245      23.976     2499.184       30.713      94.316       2.147       49.240
      6         0.30      16.735      29.304     2353.604       40.874      78.239       2.936       50.561
      7         0.35      16.229      34.632     2213.109       51.593      61.108       3.787       50.932
      8         0.40      15.714      39.960     2075.180       63.049      46.669       4.693       50.557
      9         0.45      15.193      45.288     1939.736       74.808      32.470       5.645       49.559
     10         0.50      14.662      50.616     1806.667       86.875      18.541       6.638       48.052
     11         0.55      14.121      55.944     1675.843       99.155       4.914       7.667       46.125
     12         0.60      13.568      61.272     1547.127      111.560      -8.392       8.726       43.849
     13         0.65      13.001      66.600     1420.381      124.007     -21.320       9.812       41.284
     14         0.70      12.416      71.928     1295.472      136.416     -33.870      10.921       38.480
     15         0.75      11.811      77.256     1172.273      148.709     -46.001      12.047       35.481
     16         0.80      11.181      82.584     1050.677      160.907     -57.687      13.189       32.325
     17         0.85      10.524      87.912      930.737      172.633     -69.049      14.343       29.050
     18         0.90       9.830      93.240      812.080      184.107     -79.601      15.504       25.684
     19         0.95       9.086      98.568      693.831      195.149     -90.527      18.421       22.242
     20         1.00       8.333     106.665      583.557      211.180    -112.323      19.589       18.864
     21         1.05       7.474     111.705      469.412      221.158    -116.267      20.757       15.534
     22         1.10       6.467     116.745      351.453      231.137    -120.151      21.924       12.085
     23         1.15       5.229     121.785      229.745      241.115    -123.971      23.092        8.509
     24         1.20       3.524     126.825      104.367      251.094    -127.708      24.259        4.769
```

APPENDIX E: COMPUTATION OF A CYLINDER PENETRATING END-ON

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A FLAT ENDED CYLINDER
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX       INCREMENT SIZE
C
C BWD      BULK WET DENSITY OF SEDIMENT
C
C BMASS    OBJECT MASS
C
C AMASS() ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( ) PROJECTED AREA FOR SECTION ( )
C
C CNC      BEARING CAPACITY COEFFICIENT
C
  VOL( )   VOLUME OF SECTION ( )
C
C CFOOT    BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX      DEPTH OF PENETRATION
C
C V( )     VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )    WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT       WEIGHT OF OBJECT
C
C G        ACCELERATION OF GRAVITY
C
C SPS      SHEAR STRENGTH OF SEDIMENT
C
C RAD      RADIUS
C
C WDRAG    WORK DONE BY DRAG FORCES
C
C WB( )    WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )    WORK TO SUBMERGE SECTION ( )
C
```

```
C SUMSUB()WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )    KINETIC ENERGY OF BODY AT SECTION( )
C
C
      DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
     20),WB(100),WBSUB(100),US(100),SUMSUB(100),E(100),V(100)
      DATA PI/3.141593/,G/32.1725/,AREA/100*0.0/,VOL/100*0.0/,AMASS/100*
     20.0/,DMASS/100*0.0/,SVOL/100*0.0/,WS/100*0.0/,WB/100*0.0/,WBSUB/10
     30*0.0/,US/100*0.0/,SUMSUB/100*0.0/,E/100*0.0/,V/100*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT  CYLINDER IMPACTING WITH FLAT END
      RAD=.94791
      WT=561.75
      BWD=87.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C
C     FOR A CYLINDER END ON USE A DRAG COEFFICIENT OF .9
      CD=0.9
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF CYLINDER
      Y=DX/2.
      YMAX=2.777
      Z=YMAX/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
      AREA(1)=PI*(RAD**2)
      DO 100 I=2,N
      AREA(I)=AREA(1)
  100 CONTINUE
C     FOR THIS ANALYSIS THE AREA IS CONSTANT FOR THE REMAINING
C     PENETRATION THEREFORE SET SUCCEEDING AREAS AS FOLLOWS
      DO 200 I=N,100
      AREA(I)=AREA(N)
```

```
C     PRINT,AREA(I)
  200 CONTINUE
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVOL=PI*RAD**2*YMAX
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
C     PRINT,CVOL,HAFVOL,ERROR
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE BY USING ONE HALF OF A CIRCULAR DISK, AMASS BECOMES
C     CONSTANT WHEN MAX AREA HAS BEEN REACHED.
C
      SUMVOL=0.0
      K=N+1
      DO 400 I=2,K
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
      AMASS(I-1)=BWD*(4./3.)*RAD**3
C
C     SINCE SEPARATION OCCURS AT IMPACT AMASS REMAINS CONSTANT AND THERE
C     IS NO CONTRIBUTION FROM THE DISPLACED MASS
  400 CONTINUE
C
C     AMASS REMAINS THE SAME AFTER MAX AREA
C
      DO 450 I=N,100
      AMASS(I)=AMASS(N)
C     PRINT,AMASS(N)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
```

```
C       PRINT,DMASS(N)
  500 CONTINUE
C
C
C       CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C       PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C       ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
        CT=CFOOT*CNC
        DO 600 I=1,100
        WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
C
C       CALCULATE WORK DONE BY BUOYANCY
C
        GAMMA=BWD*G
        WB(1)=(GAMMA*AREA(1)*DX**2)/2.
        SUMSUB(1)=2.0*WB(1)
        DO 700 I=2,N
C
C       WORK TO SUBMERGE SECTION
        US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C       WORK TO CONTINUE SECTION AFTER SUBMERGING
        WBSUB(I)=2.0*US(I)
C
C       TOTAL WORK OF THE SUBMERGED SECTIONS
        SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
C       TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
        WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C       AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C       SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C       THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C       ITS MAXIMUM DIMENSION
C
        DO 760 I=N,100
        WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
C       PRINT,WB(I)
  760 CONTINUE
C
C       CHECK WORK TO SUBMERGE
C
        CWB=WB(1)
```

```
          DO 800  I=2,N
          CWB=CWB+WB(I)
  800     CONTINUE
C         PRINT,CWB
C
C         ACTUAL WORK BY INTEGRATION IS
C
          X=N*DX
          AWB=(GAMMA*PI*RAD**2*X**2/2.)
C         PRINT,AWB,X
C
C
C
C
C         PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C         BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
          READ(5,2050) NNN
          WRITE(6,2060)NNN
C
          DO 1000 J=1,NNN
          WRITE(6,2200) RAD,WT,BWD,CD
C
C         READ IN THE VELOCITIES AND SHEAR STRENGTHS
          READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
          WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
          WRITE(6,2500)
C
C
C         CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
          BMASS=WT/G
          E(1)=BMASS*VO**2/2.
C
C         CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
          EP=WT*DX
C
C
C         COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
          SLOPE1=SS05/.5
          BINT1=0.0
C
          SLOPE2=(SS10-SS05)/.5
          BINT2=-SLOPE2*.5+SS05
C
          SLOPE3=(SS105-SS10)/.5
          BINT3=-SLOPE3*1.+SS10
C
```

```
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE CYLINDER TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE
C     PENETRATION DEPTH
      DEPTH=I*DX-Y
C
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
      IF(DEPTH.LE..5) GO TO 1
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
```

```
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
C
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
C     APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C     FIRST TIME OVER THE SECTION, AS DONE ABOVE
      VAVG=(V(I)+V(I+1))/2.
      IF(I.EQ.1) VAVG=(VO+V(I+1))/2.
      WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
     2S(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C     CALCULATE E AT NEXT SECTION
      E(I+1)=BMASS*V(I+1)**2/2.
C
C     CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
      EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
```

```
C
C     COMPUTE PENETRATION DEPTH
      XXX=I*DX
C
C     PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C     SECTION, SHEAR STRENGTH IN SECTION. BODY ENERGY AT END OF SECTION,
C     WORK DONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C     AND DRAG
C
      WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000 CONTINUE
 1000 CONTINUE
 2050 FORMAT(I5)
 2060 FORMAT(' ',I3)
 2100 FORMAT(F5.1,8F5.2)
 2200 FORMAT('1',60X,'CYLINDER  FLAT END IMPACTING'//9X,'RADIUS = ',
     2F7.3/9X,'WEIGHT = ',F7.1,' LBS'/
     39X,'BULK WET DENSITY = ',F5.2,'SLUGS PER CUBIC FOOT'/9X,'DRAG
     4 COEFFICIENT = ',F5.2///)
 2300 FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
     2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500 FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
     2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
     3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
     4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
     5RENGTH PSF',4X,'FT-LBS',7X.'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
     6ORCES'//)
 2600 FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
      STOP
      END
```

```
                                                  CYLINDER  FLAT END IMPACTING
RADIUS =    0.948
WEIGHT =    561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG      COEFFICIENT =  0.90


 IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.30  0.61  1.39  2.09  2.44  2.72  2.70  2.90


                 CONDITIONS AT THE END OF SECTION                        WORK DONE IN SECTION - FOOT POUNDS

   ITERATION PENETRATION    VELOCITY   SHEAR      BODY ENERGY       STATIC      SEDIMENT      BUOYANT    FORM DRAG
    SECTION      FEET        FT/SEC  STRENGTH PSF    FT-LBS          FORCES      INERTIA       FORCES     FORCES


       1          0.05       4.829      2.160      203.599         2.259       35.974        0.308       4.203
       2          0.10       4.990      6.480      217.359         6.777        2.431        0.925       4.193
       3          0.15       5.094     10.800      226.560        11.295        1.626        1.542       4.423
       4          0.20       5.147     15.120      231.278        15.813        0.834        2.159       4.562
       5          0.25       5.150     19.440      231.590        20.331        0.055        2.776       4.613
       6          0.30       5.106     23.760      227.569        24.850       -0.710        3.392       4.576
       7          0.35       5.012     28.080      219.289        29.368       -1.463        4.009       4.453
       8          0.40       4.867     32.400      206.822        33.886       -2.203        4.626       4.246
       9          0.45       4.668     36.720      190.236        38.404       -2.930        5.243       3.956
      10          0.50       4.408     41.040      169.604        42.922       -3.646        5.860       3.584
      11          0.55       4.074     45.432      144.929        47.515       -4.360        6.476       3.131
      12          0.60       3.649     49.896      116.216        52.184       -5.073        7.093       2.596
      13          0.65       3.093     54.360       83.536        56.853       -5.774        7.710       1.979
      14          0.70       2.319     58.824       46.952        61.521       -6.462        8.327       1.276
      15          0.75       0.870     63.288        6.602        66.190       -7.131        8.944       0.445
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```
                                                       CYLINDER  FLAT END IMPACTING
RADIUS =    0.948
WEIGHT =    561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG      COEFFICIENT =  0.90


 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.36  0.54  1.04  1.36  2.44  2.78  2.80  2.96


                CONDITIONS AT THE END OF SECTION                  WORK DONE IN SECTION - FOOT POUNDS

      ITERATION PENETRATION     VELOCITY   SHEAR      BODY ENERGY     STATIC     SEDIMENT     BUOYANT   FORM DRAG
       SECTION     FEET          FT/SEC  STRENGTH PSF    FT-LBS        FORCES     INERTIA      FORCES    FORCES

          1          0.05         9.266      2.592      749.511       2.711     132.433       0.308     16.151
          2          0.10         9.287      7.776      752.958       8.133       0.609       0.925     14.973
          3          0.15         9.276     12.960      751.259      13.554      -0.300       1.542     14.990
          4          0.20         9.235     18.144      744.499      18.976      -1.194       2.159     14.906
          5          0.25         9.162     23.328      732.764      24.398      -2.073       2.776     14.722
          6          0.30         9.057     28.512      716.137      29.819      -2.938       3.392     14.439
          7          0.35         8.920     33.696      694.702      35.241      -3.788       4.009     14.060
          8          0.40         8.751     38.880      668.537      40.663      -4.623       4.626     13.585
          9          0.45         8.547     44.064      637.724      46.085      -5.444       5.243     13.017
         10          0.50         8.306     49.248      602.340      51.506      -6.252       5.860     12.357
         11          0.55         8.035     53.136      563.605      55.573      -6.844       6.476     11.618
         12          0.60         7.738     55.728      522.716      58.283      -7.225       7.093     10.824
         13          0.65         7.413     58.320      479.710      60.994      -7.599       7.710      9.987
         14          0.70         7.056     60.912      434.623      63.705      -7.967       8.327      9.108
         15          0.75         6.662     63.504      387.490      66.416      -8.328       8.944      8.188
         16          0.80         6.225     66.096      338.346      69.127      -8.683       9.560      7.227
         17          0.85         5.736     68.688      287.225      71.838      -9.033      10.177      6.226
         18          0.90         5.179     71.280      234.160      74.549      -9.376      10.794      5.185
         19          0.95         4.530     73.872      179.187      77.260      -9.713      11.411      4.103
         20          1.00         3.743     76.464      122.340      79.970     -10.044      12.028      2.981
         21          1.05         2.657     81.360       61.634      85.091     -10.726      12.644      1.785
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                                                  CYLINDER  FLAT END IMPACTING
RADIUS =    0.948
WEIGHT =    561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG      COEFFICIENT =  0.00


 IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.52  0.78  1.38  2.12  2.38  2.01  2.11  1.97

                   CONDITIONS AT THE END OF SECTION                    WORK DONE IN SECTION - FOOT POUNDS

       ITERATICN PENETRATION      VELOCITY   SHEAR      BODY ENERGY       STATIC     SEDIMENT       BUOYANT    FORM DRAG
        SECTION       FEET          FT/SEC  STRENGTH PSF    FT-LBS         FORCES     INERTIA        FORCES     FORCES

           1          0.05        13.785       3.744     1658.988        3.916     293.131         0.308      36.057
           2          0.10        13.723      11.232     1644.113       11.747      -2.628         0.925      32.918
           3          0.15        13.632      18.720     1622.369       19.578      -3.842         1.542      32.553
           4          0.20        13.512      26.208     1593.871       27.410      -5.035         2.159      32.052
           5          0.25        13.362      33.696     1558.732       35.241      -6.209         2.776      31.418
           6          0.30        13.182      41.184     1517.064       43.073      -7.362         3.392      30.652
           7          0.35        12.972      48.672     1468.978       50.904      -8.497         4.009      29.758
           8          0.40        12.729      56.160     1414.579       58.735      -9.612         4.626      28.736
           9          0.45        12.453      63.648     1353.976       66.567     -10.708         5.243      27.589
          10          0.50        12.143      71.136     1287.271       74.398     -11.786         5.860      26.320
          11          0.55        11.803      76.752     1216.218       80.272     -12.555         6.476      24.947
          12          0.60        11.440      80.496     1142.540       84.187     -13.018         7.093      23.504
          13          0.65        11.052      84.240     1066.280       88.103     -13.475         7.710      22.009
          14          0.70        10.635      87.984      997.481       92.019     -13.923         8.327      20.463
          15          0.75        10.189      91.728      906.188       95.934     -14.364         8.944      18.866
          16          0.80         9.706      95.472      822.442       99.850     -14.797         9.560      17.220
          17          0.85         9.184      99.216      736.284      103.766     -15.223        10.177      15.525
          18          0.90         8.614     102.960      647.756      107.681     -15.642        10.794      13.782
          19          0.95         7.987     106.704      556.897      111.597     -16.054        11.411      11.992
          20          1.00         7.288     110.448      463.748      115.513     -16.459        12.028      10.154
          21          1.05         6.477     116.640      366.192      121.988     -17.237        12.644       8.246
          22          1.10         5.480     125.280      262.153      131.025     -18.383        13.261       6.223
          23          1.15         4.169     133.920      151.752      140.061     -19.507        13.878       4.055
          24          1.20         2.007     142.560       35.179      149.097     -20.598        14.495       1.667
```

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                                                                  CYLINDER  FLAT END IMPACTING
RADIUS =     0.948
WEIGHT =     561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG       COEFFICIENT =  0.90


 IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.69  1.04  1.43  1.06  1.97  1.57  1.65  1.76


                CONDITIONS AT THE END OF SECTION
                                                                  WORK DONE IN SECTION - FOOT POUNDS

     ITERATION PENETRATION    VELOCITY   SHEAR      BODY ENERGY     STATIC     SEDIMENT      BUOYANT    FORM DRAG
      SECTION     FEET         FT/SEC  STRENGTH PSF    FT-LBS       FORCES     INERTIA       FORCES     FORCES

        1         0.05        18.328      4.968      2932.592       5.196     518.167        0.308      63.928
        2         0.10        18.204     14.904      2893.084      15.587      -6.981        0.925      58.057
        3         0.15        18.052     24.840      2844.961      25.979      -8.503        1.542      57.184
        4         0.20        17.872     34.776      2788.373      36.371      -9.999        2.159      56.140
        5         0.25        17.662     44.712      2723.455      46.762     -11.470        2.776      54.929
        6         0.30        17.424     54.648      26[illegible].352      57.154     -12.917        3.392      53.553
        7         0.35        17.155     64.584      2569.197      67.546     -14.340        4.009      52.016
        8         0.40        16.855     74.520      2480.131      77.937     -15.737        4.626      50.319
        9         0.45        16.522     84.456      2393.289      88.329     -17.111        5.243      48.466
       10         0.50        16.156     94.392      2273.795      98.720     -18.463        5.860      46.459
       11         0.55        15.762    101.380      2168.941     106.552     -19.410        6.476      44.322
       12         0.60        15.346    105.920      2055.971     111.823     -19.961        7.093      42.101
       13         0.65        14.907    111.960      1939.937     117.094     -20.502        7.710      39.818
       14         0.70        14.442    117.000      1820.891     122.365     -21.034        8.327      37.474
       15         0.75        13.950    122.040      1693.885     127.636     -21.557        8.944      35.071
       16         0.80        13.427    127.080      1573.967     132.907     -22.072        9.560      32.609
       17         0.85        12.871    132.120      1446.187     138.179     -22.578       10.177      30.089
       18         0.90        12.276    137.160      1315.593     143.450     -23.075       10.794      27.513
       19         0.95        11.637    142.200      1192.232     148.721     -23.564       11.411      24.880
       20         1.00        10.947    147.240      1046.152     153.992     -24.044       12.028      22.192
       21         1.05        10.194    152.568       907.145     159.564     -24.562       12.644      19.447
       22         1.10         9.361    158.184       765.008     165.438     -25.115       13.261      16.640
       23         1.15         8.426    163.800       619.795     171.311     -25.658       13.878      13.769
       24         1.20         7.349    169.416       471.562     177.185     -26.192       14.495      10.832
       25         1.25         6.058    175.032       320.367     183.058     -26.715       15.112       7.826
       26         1.30         4.364    180.643       166.286     188.932     -27.225       15.728       4.733
       27         1.35         1.049    186.264         9.614     194.805     -27.683       16.345       1.292
```

```
IMPACT VELOCITY EQUALS  0.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE      CYLINDER  FLAT END IMPACTING
      0.21  0.35  0.52  1.10  2.30  2.78  2.56  3.10
                                                                      RADIUS =      0.948
                                                                      HEIGHT =      561.0 LBS
                                                                      BULK WET DENSITY =    2.72SLUGS PER CUBIC FOOT
                                                                      DRAG     COEFFICIENT =  0.90
                CONDITIONS AT THE END OF SECTION
                                                                            WORK DONE IN SECTION - FOOT POUNDS
  ITERATION PENETRATION    VELOCITY    SHEAR      BODY ENERGY
   SECTION     FEET         FT/SEC  STRENGTH PSF     FT-LBS        STATIC      SEDIMENT      BUOYANT      FORM DRAG
                                                                   FORCES      INERTIA       FORCES       FORCES

     1         0.05         1.594       1.512       22.170          1.581       3.917         0.308        0.110
     2         0.10         2.159       4.536       40.702          4.744       3.274         0.925        0.612
     3         0.15         2.527       7.560       55.731          7.907       2.655         1.542        0.955
     4         0.20         2.777      10.584       67.320         11.069       2.048         2.159        1.223
     5         0.25         2.945      13.608       75.527         14.232       1.450         2.776        1.422
     6         0.30         3.035      16.632       80.411         17.395       0.863         3.392        1.553
     7         0.35         3.065      19.656       82.028         20.557       0.286         4.009        1.619
     8         0.40         3.035      22.680       80.432         23.720      -0.282         4.626        1.619
     9         0.45         2.944      25.704       75.678         26.883      -0.840         5.243        1.556
    10         0.50         2.787      28.728       67.820         30.045      -1.389         5.860        1.429
    11         0.55         2.563      31.248       57.354         32.491      -1.849         6.476        1.246
    12         0.60         2.264      33.264       44.768         34.789      -2.224         7.093        1.014
    13         0.65         1.857      35.280       30.100         36.898      -2.592         7.710        0.740
    14         0.70         1.238      37.296       13.389         39.006      -2.953         8.327        0.418


IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.87  1.04  1.04  1.41  1.13  1.48  1.87  1.76


                CONDITIONS AT THE END OF SECTION
                                                                            WORK DONE IN SECTION - FOOT POUNDS
  ITERATION PENETRATION    VELOCITY    SHEAR      BODY ENERGY
   SECTION     FEET         FT/SEC  STRENGTH PSF     FT-LBS        STATIC      SEDIMENT      BUOYANT      FORM DRAG
                                                                   FORCES      INERTIA       FORCES       FORCES

     1         0.05         4.786       6.264      199.982          6.551      35.335         0.308        4.167
     2         0.10         4.821      18.792      202.951         19.654       0.524         0.925        4.015
     3         0.15         4.718      31.370      194.308         32.756      -1.527         1.542        3.959
     4         0.20         4.468      43.648      174.250         45.859      -3.544         2.159        3.671
     5         0.25         4.047      56.376      142.973         58.961      -5.527         2.776        3.155
     6         0.30         3.396      68.904      100.667         72.064      -7.475         3.392        2.411
     7         0.35         2.333      81.432       47.537         85.166      -9.388         4.009        1.431
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                                                   CYLINDER  FLAT END IMPACTING
RADIUS =    0.948
WEIGHT =    561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG       COEFFICIENT =   0.90


 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.24  0.33  0.71  0.87  1.74  1.74  1.79  1.81


              CONDITIONS AT THE END OF SECTION                  WORK DONE IN SECTION - FOOT POUNDS

   ITERATION PENETRATION    VELOCITY   SHEAR      BODY ENERGY      STATIC     SEDIMENT     BUOYANT     FORM DRAG
    SECTION     FEET         FT/SEC  STRENGTH PSF   FT-LBS         FORCES     INERTIA      FORCES      FORCES

       1        0.05         9.270      1.728      750.272         1.807     132.568        0.308      16.159
       2        0.10         9.306      5.184      755.991         5.422       1.010        0.925      15.010
       3        0.15         9.318      8.640      758.048         9.036       0.363        1.542      15.088
       4        0.20         9.309     12.096      756.505        12.651      -0.273        2.159      15.093
       5        0.25         9.277     15.552      751.422        16.265      -0.898        2.776      15.027
       6        0.30         9.224     19.008      742.859        19.880      -1.513        3.392      14.892
       7        0.35         9.150     22.464      730.873        23.494      -2.118        4.009      14.687
       8        0.40         9.053     25.920      715.523        27.109      -2.712        4.626      14.414
       9        0.45         8.934     29.376      696.865        30.723      -3.297        5.243      14.075
      10        0.50         8.793     32.832      674.955        34.338      -3.871        5.860      13.671
      11        0.55         8.634     35.208      650.200        36.822      -4.268        6.476      13.212
      12        0.60         8.464     36.504      625.383        38.178      -4.490        7.093      12.718
      13        0.65         8.281     37.800      599.741        39.533      -4.708        7.710      12.199
      14        0.70         8.086     39.096      570.879        40.889      -4.923        8.327      11.655
      15        0.75         7.878     40.392      541.824        42.244      -5.134        8.944      11.088
      16        0.80         7.655     41.688      511.595        43.600      -5.341        9.560      10.497
      17        0.85         7.417     42.984      480.212        44.955      -5.545       10.177       9.883
      18        0.90         7.161     44.280      447.695        46.310      -5.746       10.794       9.246
      19        0.95         6.887     45.576      414.061        47.666      -5.943       11.411       8.586
      20        1.00         6.592     46.872      379.331        49.021      -6.137       12.028       7.904
      21        1.05         6.256     50.256      341.683        52.560      -6.652       12.644       7.182
      22        1.10         5.855     55.728      299.327        58.283      -7.434       13.261       6.383
      23        1.15         5.376     61.200      252.341        64.006      -8.302       13.878       5.490
      24        1.20         4.796     66.672      200.807        69.729      -9.106       14.495       4.503
      25        1.25         4.073     72.144      144.802        75.452      -9.896       15.112       3.424
      26        1.30         3.109     77.616       84.410        81.175     -10.671       15.728       2.247
      27        1.35         1.504     83.088       19.749        86.898     -11.425       16.345       0.930
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                                                  CYLINDER  FLAT END IMPACTING
RADIUS =    0.948
WEIGHT =    561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG      COEFFICIENT =  0.90


 IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.66  1.00  1.07  0.87  1.20  1.57  1.43  1.50


                 CONDITIONS AT THE END OF SECTION                  WORK DONE IN SECTION - FOOT POUNDS

      ITERATICN PENETRATION    VELOCITY   SHEAR     BODY ENERGY     STATIC     SEDIMENT      BUOYANT    FORM DRAG
       SECTION      FEET        FT/SEC  STRENGTH PSF   FT-LBS        FORCES     INERTIA       FORCES     FORCES

          1          0.05       13.781      4.752     1658.100       4.970     292.974        0.308      36.048
          2          0.10       13.708     14.256     1640.575      14.910      -3.096        0.925      32.873
          3          0.15       13.599     23.760     1614.448      24.850      -4.616        1.542      32.439
          4          0.20       13.452     33.264     1579.864      34.789      -6.111        2.159      31.833
          5          0.25       13.268     42.768     1536.965      44.729      -7.580        2.776      31.061
          6          0.30       13.046     52.272     1485.891      54.669      -9.075        3.392      30.124
          7          0.35       12.784     61.776     1425.779      64.609     -10.445        4.009      29.026
          8          0.40       12.480     71.280     1359.764      74.549     -11.841        4.626      27.768
          9          0.45       12.132     80.784     1284.979      84.488     -13.214        5.243      26.354
         10          0.50       11.737     90.288     1202.556      94.428     -14.564        5.860      24.786
         11          0.55       11.299     97.488     1114.652     101.958     -15.532        6.476      23.088
         12          0.60       10.827    102.384     1023.391     107.079     -16.125        7.093      21.301
         13          0.65       10.315    107.280      925.829     112.199     -16.708        7.710      19.447
         14          0.70        9.756    112.176      831.022     117.320     -17.282        8.327      17.528
         15          0.75        9.144    117.072      730.025     122.441     -17.845        8.944      15.545
         16          0.80        8.467    121.968      625.893     127.561     -18.399        9.560      13.497
         17          0.85        7.708    126.864      518.679     132.682     -18.944       10.177      11.386
         18          0.90        6.840    131.760      408.438     137.802     -19.479       10.794       9.211
         19          0.95        5.815    136.656      295.223     142.923     -20.004       11.411       6.972
         20          1.00        4.529    141.552      179.097     148.043     -20.519       12.028       4.660
         21          1.05        2.562    144.504       61.867     151.130     -20.714       12.644       2.256
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RADIUS =     0.948                                    CYLINDER  FLAT END IMPACTING
WEIGHT =     561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG       COEFFICIENT =  0.90

 IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.50  0.75  1.18  1.37  1.53  2.26  1.91  2.02

               CONDITIONS AT THE END OF SECTION
                                                                   WORK DONE IN SECTION - FOOT POUNDS
     ITERATION PENETRATION    VELOCITY   SHEAR        BODY ENERGY
      SECTION     FEET         FT/SEC  STRENGTH PSF      FT-LBS        STATIC     SEDIMENT     BUOYANT    FORM DRAG
                                                                       FORCES     INERTIA      FORCES     FORCES
         1         0.05       13.786       3.600      1659.115        3.765     293.153       0.308      36.058
         2         0.10       13.725      10.800      1644.619       11.295      -2.561       0.925      32.924
         3         0.15       13.637      18.000      1622.561       18.825      -3.731       1.542      32.569
         4         0.20       13.522      25.200      1595.872       26.356      -4.882       2.159      32.083
         5         0.25       13.375      32.400      1561.842       33.896      -6.013       2.776      31.469
         6         0.30       13.202      39.600      1521.518       41.416      -7.125       3.392      30.728
         7         0.35       12.998      46.800      1475.006       48.946      -8.218       4.009      29.862
         8         0.40       12.764      54.000      1422.410       56.476      -9.293       4.626      28.874
         9         0.45       12.499      61.200      1365.832       64.006     -10.350       5.243      27.766
        10         0.50       12.200      68.400      1293.374       71.537     -11.389       5.860      26.539
        11         0.55       11.873      73.800      1230.719       77.184     -12.131       6.476      25.212
        12         0.60       11.525      77.400      1159.525       80.949     -12.579       7.093      23.818
        13         0.65       11.152      81.000      1085.835       84.714     -13.021       7.710      22.373
        14         0.70       10.754      84.600      1009.691       88.479     -13.454       8.327      20.879
        15         0.75       10.327      88.200       931.133       92.245     -13.880       8.944      19.337
        16         0.80        9.868      91.800       850.204       96.010     -14.300       9.560      17.746
        17         0.85        9.373      95.400       766.942       99.775     -14.712      10.177      16.109
        18         0.90        8.835      99.000       681.387      103.540     -15.117      10.794      14.424
        19         0.95        8.246     102.600       593.579      107.305     -15.515      11.411      12.694
        20         1.00        7.595     106.200       503.556      111.070     -15.906      12.028      10.919
        21         1.05        6.855     111.096       410.214      116.190     -16.493      12.644       9.086
        22         1.10        5.983     117.288       312.470      122.666     -17.271      13.261       7.173
        23         1.15        4.909     123.480       210.406      129.142     -18.034      13.878       5.165
        24         1.20        3.453     129.672       104.114      135.618     -18.781      14.495       3.048
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                                                   CYLINDER  FLAT END IMPACTING
RADIUS =     0.948
WEIGHT =     561.8 LBS
BULK WET DENSITY =   2.72SLUGS PER CUBIC FOOT
DRAG       COEFFICIENT =   0.90


 IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.73  1.00  0.99  1.08  1.52  1.91  2.39  2.95


                 CONDITIONS AT THE END OF SECTION                    WORK DONE IN SECTION - FOOT POUNDS

      ITERATION PENETRATION     VELOCITY   SHEAR      BODY ENERGY       STATIC     SEDIMENT      BUOYANT   FORM DRAG
       SECTION     FEET          FT/SEC  STRENGTH PSF    FT-LBS         FORCES     INERTIA       FORCES    FORCES

          1          0.05         18.327      5.256     2932.336         5.497     518.122        0.308     63.926
          2          0.10         18.201     15.768     2892.072        16.491      -7.115        0.925     58.044
          3          0.15         18.045     26.290     2842.699        27.485      -8.724        1.542     57.151
          4          0.20         17.859     36.792     2784.369        38.479     -10.307        2.159     56.078
          5          0.25         17.642     47.304     2717.238        49.473     -11.861        2.776     54.827
          6          0.30         17.394     57.816     2641.445        60.467     -13.392        3.392     53.403
          7          0.35         17.114     68.328     2557.146        71.461     -14.895        4.009     51.807
          8          0.40         16.802     78.840     2464.477        82.455     -16.374        4.626     50.043
          9          0.45         16.454     89.352     2363.582        93.449     -17.827        5.243     48.113
         10          0.50         16.070     99.864     2254.598       104.443     -19.257        5.860     46.021
         11          0.55         15.659    107.064     2140.582       111.974     -20.146        6.476     43.798
         12          0.60         15.228    110.952     2024.536       116.040     -20.505        7.093     41.504
         13          0.65         14.778    114.840     1906.493       120.106     -20.857        7.710     39.171
         14          0.70         14.305    118.728     1786.486       124.172     -21.204        8.327     36.798
         15          0.75         13.808    122.616     1664.550       128.239     -21.545        8.944     34.386
         16          0.80         13.285    126.504     1540.717       132.305     -21.880        9.560     31.935
         17          0.85         12.731    130.392     1415.018       136.371     -22.210       10.177     29.447
         18          0.90         12.144    134.280     1287.485       140.438     -22.534       10.794     26.922
         19          0.95         11.518    138.168     1158.149       144.504     -22.853       11.411     24.360
         20          1.00         10.846    142.056     1027.041       148.570     -23.166       12.028     21.763
         21          1.05         10.131    143.928      895.969       150.528     -23.160       12.644     19.147
         22          1.10          9.371    143.784      766.706       150.377     -22.840       13.261     16.550
         23          1.15          8.557    143.640      639.226       150.227     -22.525       13.878     13.988
         24          1.20          7.669    143.496      513.498       150.076     -22.215       14.495     11.459
         25          1.25          6.679    143.352      389.496       149.926     -21.910       15.112      8.962
         26          1.30          5.532    143.208      267.196       149.775     -21.609       15.728      6.493
         27          1.35          4.098    143.064      146.584       149.624     -21.311       16.345      4.040
         28          1.40          1.782    142.920       27.726       149.474     -21.001       16.962      1.512
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RADIUS =     0.948                                          CYLINDER  FLAT END IMPACTING
WEIGHT =     561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG       COEFFICIENT =  0.90


 IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.21  0.31  0.60  1.44  1.44  2.44  2.55  2.44

                  CONDITIONS AT THE END OF SECTION
                                                                           WORK DONE IN SECTION - FOOT POUNDS
     ITERATION PENETRATION    VELOCITY    SHEAR    BODY ENERGY
      SECTION      FEET        FT/SEC  STRENGTH PSF   FT-LBS       STATIC     SEDIMENT      BUOYANT     FORM DRAG
                                                                   FORCES     INERTIA       FORCES      FORCES

         1         0.05        4.836       1.512     204.170       1.581     36.075        0.308       4.209
         2         0.10        5.016       4.536     219.634       4.744      2.732        0.925       4.221
         3         0.15        5.151       7.560     231.652       7.907      2.124        1.542       4.496
         4         0.20        5.246      10.584     240.284      11.069      1.525        2.159       4.702
         5         0.25        5.304      13.608     245.585      14.232      0.937        2.776       4.842
         6         0.30        5.326      16.632     247.611      17.395      0.358        3.392       4.915
         7         0.35        5.313      19.656     246.419      20.557     -0.211        4.009       4.923
         8         0.40        5.266      22.680     242.061      23.720     -0.770        4.626       4.868
         9         0.45        5.184      25.704     234.592      26.883     -1.320        5.243       4.750
        10         0.50        5.066      28.728     224.063      30.045     -1.860        5.860       4.571
        11         0.55        4.919      30.960     211.225      32.380     -2.268        6.476       4.337
        12         0.60        4.748      32.400     196.814      33.886     -2.546        7.093       4.066
        13         0.65        4.551      33.840     180.856      35.392     -2.820        7.710       3.763
        14         0.70        4.326      35.280     163.378      36.898     -3.038        8.327       3.429
        15         0.75        4.067      36.720     144.405      38.404     -3.352        8.944       3.065
        16         0.80        3.768      38.160     123.963      39.910     -3.612        9.560       2.671
        17         0.85        3.419      39.600     102.076      41.416     -3.867       10.177       2.248
        18         0.90        3.004      41.040      78.770      42.922     -4.118       10.794       1.796
        19         0.95        2.489      42.480      54.070      44.428     -4.364       11.411       1.313
        20         1.00        1.791      43.920      28.003      45.934     -4.606       12.028       0.798
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                                                     CYLINDER  FLAT END IMPACTING
RADIUS =    0.948
WEIGHT =    561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG      COEFFICIENT =  0.90


 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.21  0.57  1.46  2.11  2.05  2.07  2.09  2.30


                  CONDITIONS AT THE END OF SECTION                WORK DONE IN SECTION - FOOT POUNDS

 ITERATION PENETRATION    VELOCITY   SHEAR      BODY ENERGY      STATIC     SEDIMENT      BUOYANT    FORM DRAG
  SECTION      FEET        FT/SEC  STRENGTH PSF    FT-LBS        FORCES     INERTIA       FORCES     FORCES

     1          0.05        9.272      1.512      750.462        1.581     132.601        0.308      16.161
     2          0.10        9.310      4.536      756.749        4.744       1.111        0.925      15.020
     3          0.15        9.329      7.560      759.746        7.907       0.529        1.542      15.112
     4          0.20        9.327     10.584      759.507       11.069      -0.042        2.159      15.140
     5          0.25        9.306     13.608      756.087       14.232      -0.604        2.776      15.104
     6          0.30        9.256     16.632      749.539       17.395      -1.157        3.392      15.005
     7          0.35        9.206     19.656      739.916       20.557      -1.700        4.009      14.843
     8          0.40        9.127     22.680      727.270       23.720      -2.234        4.626      14.622
     9          0.45        9.029     25.704      711.651       26.883      -2.760        5.243      14.340
    10          0.50        8.910     28.728      693.109       30.045      -3.276        5.860      13.999
    11          0.55        8.765     32.832      670.743       34.338      -3.952        6.476      13.592
    12          0.60        8.586     38.016      643.663       39.759      -4.785        7.093      13.098
    13          0.65        8.372     43.200      611.950       45.181      -5.603        7.710      12.512
    14          0.70        8.120     48.384      575.682       50.603      -6.408        8.327      11.834
    15          0.75        7.828     53.568      534.935       56.024      -7.200        8.944      11.066
    16          0.80        7.490     58.752      489.784       61.446      -7.978        9.560      10.209
    17          0.85        7.102     63.936      440.304       66.868      -8.743       10.177       9.264
    18          0.90        6.654     69.120      386.568       72.290      -9.495       10.794       8.234
    19          0.95        6.136     74.304      328.648       77.711     -10.234       11.411       7.118
    20          1.00        5.526     79.488      266.616       83.133     -10.961       12.028       5.919
    21          1.05        4.752     88.488      197.182       92.545     -12.268       12.644       4.599
    22          1.10        3.663    101.304      117.121      105.949     -14.146       13.261       3.084
    23          1.15        1.743    114.120       26.679      119.353     -15.920       13.878       1.279
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RADIUS =     0.948                                                   CYLINDER  FLAT END IMPACTING
WEIGHT =     561.8 LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG       COEFFICIENT =  0.90


  IMPACT VELOCITY EQUALS 15.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
        0.36  0.45  0.40  1.22  1.39  1.74  2.35  2.90


                     CONDITIONS AT THE END OF SECTION
                                                                          WORK DONE IN SECTION - FOOT POUNDS
         ITERATION PENETRATION     VELOCITY   SHEAR       BODY ENERGY
          SECTION      FEET         FT/SEC  STRENGTH PSF     FT-LBS        STATIC      SEDIMENT       BUOYANT      FORM DRAG
                                                                           FORCES      INERTIA        FORCES       FORCES

            1          0.05         13.789      2.592     1660.002          2.711      293.310         0.308        36.068
            2          0.10         13.740      7.776     1648.157          8.133       -2.093         0.925        32.968
            3          0.15         13.670     12.960     1631.422         13.554       -2.957         1.542        32.683
            4          0.20         13.579     18.144     1609.879         18.976       -3.807         2.159        32.302
            5          0.25         13.468     23.328     1583.609         24.398       -4.642         2.776        31.825
            6          0.30         13.335     28.512     1552.692         29.819       -5.463         3.392        31.255
            7          0.35         13.183     33.696     1517.205         35.241       -6.270         4.009        30.594
            8          0.40         13.008     38.880     1477.226         40.663       -7.064         4.626        29.841
            9          0.45         12.811     44.064     1432.829         46.085       -7.844         5.243        29.000
           10          0.50         12.591     49.248     1384.091         51.506       -8.612         5.860        28.072
           11          0.55         12.356     52.488     1332.795         54.895       -9.063         6.476        27.075
           12          0.60         12.112     53.784     1280.699         56.250       -9.205         7.093        26.044
           13          0.65         11.850     55.080     1227.816         57.606       -9.344         7.710        24.998
           14          0.70         11.597     56.376     1174.159         58.961       -9.481         8.327        23.936
           15          0.75         11.325     57.672     1119.742         60.317       -9.615         8.944        22.859
           16          0.80         11.043     58.968     1064.577         61.672       -9.747         9.560        21.767
           17          0.85         10.749     60.264     1008.677         63.027       -9.877        10.177        20.660
           18          0.90         10.443     61.560      952.054         64.383      -10.005        10.794        19.538
           19          0.95         10.123     62.856      894.720         65.738      -10.130        11.411        18.402
           20          1.00          9.790     64.152      836.688         67.094      -10.254        12.028        17.252
           21          1.05          9.445     64.440      778.856         67.395      -10.218        12.644        16.097
           22          1.10          9.095     63.720      722.112         66.642      -10.026        13.261        14.955
           23          1.15          8.737     63.000      666.435         65.889       -9.838        13.878        13.834
           24          1.20          8.371     62.280      611.808         65.136       -9.652        14.495        12.735
           25          1.25          7.996     61.560      558.214         64.383       -9.470        15.112        11.656
           26          1.30          7.610     60.840      505.635         63.630       -9.290        15.728        10.598
           27          1.35          7.212     60.120      454.054         62.877       -9.114        16.345         9.559
           28          1.40          6.798     59.400      403.455         62.124       -8.940        16.962         8.540
           29          1.45          6.366     58.680      353.821         61.371       -8.770        17.579         7.541
           30          1.50          5.912     57.960      305.137         60.618       -8.602        18.196         6.560
           31          1.55          5.371     63.504      251.867         66.416       -9.412        18.812         5.540
           32          1.60          4.648     75.312      188.574         78.765      -11.183        19.429         4.369
           33          1.65          3.636     87.120      115.435         91.115      -12.923        20.046         2.989
           34          1.70          1.934     98.928       32.665        103.464      -14.625        20.663         1.355
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                                                                      FLAT END IMPACTING
RADIUS =      0.948
WEIGHT =      561.8 LBS
BULK WET DENSITY =   2.72SLUGS PER CUBIC FOOT
DRAG        COEFFICIENT =   0.90


  IMPACT VELOCITY EQUALS 20.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
         0.70   1.04   1.39   2.26   2.32   2.70   2.79   2.76


                      CONDITIONS AT THE END OF SECTION
                                                                     WORK DONE IN SECTION - FOOT POUNDS
        ITERATION PENETRATION      VELOCITY    SHEAR      BODY ENERGY
         SECTION       FEET          FT/SEC   STRENGTH PSF    FT-LBS        STATIC       SEDIMENT        BUOYANT       FORM DRAG
                                                                            FORCES       INERTIA         FORCES        FORCES

            1          0.05          18.328       5.040      2932.529        5.271       518.156          0.308         63.928
            2          0.10          18.203      15.120      2892.832       15.813        -7.014          0.925         58.054
            3          0.15          18.050      25.200      2844.398       26.356        -8.558          1.542         57.175
            4          0.20          17.868      35.280      2787.373       36.898       -10.076          2.159         56.124
            5          0.25          17.657      45.360      2721.904       47.440       -11.568          2.776         54.904
            6          0.30          17.416      55.440      2648.129       57.982       -13.035          3.392         53.516
            7          0.35          17.145      65.520      2566.191       68.524       -14.478          4.009         51.964
            8          0.40          16.842      75.600      2476.227       79.067       -15.896          4.626         50.250
            9          0.45          16.505      85.680      2378.369       89.609       -17.291          5.243         48.378
           10          0.50          16.135      95.760      2272.754      100.151       -18.661          5.860         46.349
           11          0.55          15.736     103.248      2161.795      107.983       -19.605          6.476         44.190
           12          0.60          15.316     108.144      2047.867      113.103       -20.130          7.093         41.949
           13          0.65          14.872     113.040      1931.017      118.224       -20.646          7.710         39.648
           14          0.70          14.404     117.936      1811.296      123.344       -21.154          8.327         37.290
           15          0.75          13.908     122.832      1688.753      128.465       -21.652          8.944         34.874
           16          0.80          13.392     127.728      1563.434      133.595       -22.143          9.560         32.403
           17          0.85          12.822     132.624      1435.387      138.706       -22.625         10.177         29.877
           18          0.90          12.225     137.520      1304.656      143.826       -23.099         10.794         27.296
           19          0.95          11.583     142.416      1171.289      149.947       -23.565         11.411         24.662
           20          1.00          10.890     147.312      1035.329      154.067       -24.023         12.028         21.975
           21          1.05          10.135     152.280       896.758      159.253       -24.484         12.644         19.235
           22          1.10           9.303     157.320       755.556      164.534       -24.949         13.261         16.442
           23          1.15           8.371     162.360       611.771      169.805       -25.406         13.878         13.595
           24          1.20           7.302     167.400       465.449      175.076       -25.854         14.495         10.692
           25          1.25           6.022     172.440       316.640      180.347       -26.293         15.112          7.730
           26          1.30           4.353     177.480       165.411      185.619       -26.721         15.728          4.690
           27          1.35           1.174     182.520        12.023      190.890       -27.103         16.345          1.343
```

APPENDIX F: COMPUTATION OF THE PENETRATION OF A CUBE

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A CUBE
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX       INCREMENT SIZE
C
C BWD      BULK WET DENSITY OF SEDIMENT
C
C BMASS    OBJECT MASS
C
C AMASS()  ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( )  PROJECTED AREA FOR SECTION ( )
C
C CNC      BEARING CAPACITY COEFFICIENT
C
C VOL( )   VOLUME OF SECTION ( )
C
C CFOOT    BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX      DEPTH OF PENETRATION
C
C SVOL( )  SUM OF VOLUMES TO SECTION INDICATED
C
C V( )     VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )    WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT       WEIGHT OF OBJECT
C
C G        ACCELERATION OF GRAVITY
C
C SPS      SHEAR STRENGTH OF SEDIMENT
C
C RAD      RADIUS OF AN EQUIVALENT CROSS SECTIONAL AREA
C
C DIM      LENGTH OF ONE SIDE
C
C WDRAG    WORK DONE BY DRAG FORCES
C
C WB( )    WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
```

```
C
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )   WORK TO SUBMERGE SECTION ( )
C
C SUMSUB()WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )    KINETIC ENERGY OF BODY AT SECTION( )
C
C
      DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
     20),WB(100),WBSUB(50),US(50),SUMSUB(50),E(100),V(100)
C     RESET DIMENSIONS FOR LARGE OBJECTS
      DATA PI/3.141593/,G/32.1725/,AREA/100*0.0/,VOL/100*0.0/,AMASS/100*
     20.0/,DMASS/100*0.0/,SVOL/100*0.0/,WS/100*0.0/,WB/100*0.0/,WBSUB/50
     3*0.0/,US/50*0.0/,SUMSUB/50*0.0/,E/100*0.0/,V/100*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT CUBE
      DIM=2.0
C     THE RADIUS OF AN EQUIVALENT CIRCULAR AREA IS.
      RAD=SQRT(DIM**2/PI)
      WT=702.75
      BWD=87.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C
C     FOR A CUBE USE A COEFFICIENT OF DRAG EQUAL TO 1.1
      CD=1.1
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF CUBE
      Y=DX/2.
      Z=DIM/DX
      N=Z+1
      AREA(1)=DIM**2
C
```

```
C     FOR THIS ANALYSIS THE AREA IS
C     CONSTANT FOR THE REMAINING PENETRATION THEREFORE SET SUCCEEDING
C     AREAS AS FOLLOWS
      DO 200 I=1,100
      AREA(I)=AREA(1)
C     PRINT, AREA(I)
  200 CONTINUE
C
C
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVOL=DIM**3
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
C     PRINT,CVOL,HAFVOL,ERROR
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE BY USING ONE HALF OF A CIRCULAR DISK WITH AN
C     EQUIVALENT AREA
C     AMASS BECOMES CONSTANT WHEN THE MAXIMUM AREA HAS BEEN REACHED.
C
      SUMVOL=0.0
      K=N+1
      DO 400 I=2,K
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
      AMASS(I-1)=BWD*(4./3.)*RAD**3
C
C     SINCE SEPARATION OCCURS AT IMPACT AMASS REMAINS CONSTANT AND THERE
C     IS NO CONTRIBUTION FROM THE DISPLACED MASS
C
  400 CONTINUE
C
      DO 450 I=N,100
      AMASS(I)=AMASS(N)
```

```
C     PRINT,AMASS(I)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500  I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
C     PRINT,DMASS(I)
  500 CONTINUE
C
C     SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C
      CDMASS=DMASS(1)
      DO 550  I=2,N
      CDMASS=CDMASS+DMASS(I)
  550 CONTINUE
C     PRINT,CDMASS,AMASS(N)
C
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600  I=1,100
      WS(I)=CT*COH*AREA(I)*DX
C     PRINT,WS(I)
  600 CONTINUE
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY
C
C
      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700  I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
```

```
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
C     PRINT,WB(I)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
C     PRINT,CWB
C
C     ACTUAL WORK BY INTEGRATION IS
C
      X=N*DX
      AWB=(GAMMA*DIM**2*X**2/2.)
C     PRINT,AWB,X
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) DIM,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
```

```
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
      SLOPE1=SS05/.5
      BINT1=0.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NCTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE CUBE TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE PENETRA
C     TION DEPTH
      DEPTH=I*DX-Y
C
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
```

```
      IF(DEPTH.LE..5) GO TO 1
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
C
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
```

```
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
C     APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C     FIRST TIME OVER THE SECTION, AS DONE ABOVE
      VAVG=(V(I)+V(I+1))/2.
      IF(I.EQ.1) VAVG=(V0+V(I+1))/2.
      WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
     2S(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C     CALCULATE E AT NEXT SECTION
      E(I+1)=BMASS*V(I+1)**2/2.
C
C     CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
      EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C     COMPUTE PENETRATION DEPTH
      XXX=I*DX
C
C     PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C     SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C     WORK DONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C     AND DRAG
C
      WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000 CONTINUE
 1000 CONTINUE
 2050 FORMAT(I5)
 2060 FORMAT(' ',I3)
 2100 FORMAT(F5.1,8F5.2)
 2200 FORMAT('1',60X,'CUBE'//9X,'SIDE    = ',F7.3/9X,'WEIGHT = ',F7.1,'
     2LBS'/9X,'BULK WET DENSITY = ',F5.2,'SLUGS PER CUBIC FOOT'/9X,'DRAG
     3 COEFFICIENT = ',F5.2///)
 2300 FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
     2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500 FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
     2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
     3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
     4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
     5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
     6ORCES'//)
 2600 FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
      STOP
      END
```

```
                                              CURE
SIDE    =    2.000
WEIGHT =    702.8  LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.10


  IMPACT VELOCITY EQUALS  0.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
         0.48  0.85  1.30  1.70  2.00  1.75  1.40  1.20

                   CONDITIONS AT THE END OF SECTION
                                                                    WORK DONE IN SECTION - FOOT POUNDS
       ITERATION PENETRATION      VELOCITY   SHEAR     BODY ENERGY
        SECTION     FEET          FT/SEC  STRENGTH PSF   FT-LBS        STATIC      SEDIMENT       BUOYANT    FORM DRAG
                                                                       FORCES      INERTIA        FORCES     FORCES
          1          0.05          1.475       3.456      23.756
          2          0.10          1.865      10.368      27.985         5.122       5.660       0.437       0.163
          3          0.15          1.984      17.280      43.012        15.365       3.390       1.311       0.842
          4          0.20          1.891      24.192      39.047        25.609       1.198       2.185       1.119
          5          0.25          1.552      31.104      26.297        35.953      -0.945       3.059       1.135
          6          0.30          0.676      38.016       4.987        46.096      -3.039       3.933       0.896
                                                                        56.340      -5.077       4.807       0.377

 IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.80  1.04  1.13  0.87  1.23  1.53  1.54  1.54

                  CONDITIONS AT THE END OF SECTION
                                                                   WORK DONE IN SECTION - FOOT POUNDS
      ITERATION PENETRATION      VELOCITY   SHEAR     BODY ENERGY
       SECTION     FEET          FT/SEC  STRENGTH PSF   FT-LBS        STATIC      SEDIMENT       BUOYANT    FORM DRAG
                                                                      FORCES      INERTIA        FORCES     FORCES
         1          0.05          4.648       5.760     235.954
         2          0.10          4.661      17.280     237.303         8.536      56.215       0.437       7.035
         3          0.15          4.532      28.800     224.289        25.609       0.321       1.311       6.547
         4          0.20          4.250      40.320     197.231        42.682      -3.101       2.185       6.385
         5          0.25          3.785      51.840     156.446        59.754      -6.446       3.059       5.827
         6          0.30          3.060      63.360     102.246        76.827      -9.717       3.933       4.880
         7          0.35          1.790      74.880      34.975        93.899     -12.913       4.807       3.543
                                                                      110.972     -16.027       5.681       1.783
```

```
                                                     CUBE
SIDE   =    2.000
WEIGHT =    702.8  LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.10


 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE APE
      0.50  0.71  1.01  2.00  2.05  2.10  2.38  2.10

               CONDITIONS AT THE END OF SECTION                     WORK DONE IN SECTION - FOOT POUNDS

   ITERATION PENETRATION     VELOCITY   SHEAR      BODY ENERGY      STATIC     SEDIMENT      BUOYANT    FORM DRAG
    SECTION       FEET        FT/SEC  STRENGTH PSF    FT-LBS         FORCES     INERTIA       FORCES     FORCES

       1          0.05        8.995      3.600      883.711         5.335    210.540        0.437      27.273
       2          0.10        8.968     10.800      878.416        16.006     -1.261        1.311      24.376
       3          0.15        8.894     18.000      864.018        26.676     -3.430        2.135      24.104
       4          0.20        8.774     25.200      840.718        37.346     -5.551        3.059      23.583
       5          0.25        8.605     32.400      808.712        48.017     -7.625        3.933      22.817
       6          0.30        8.387     39.600      768.195        58.687     -9.653        4.807      21.813
       7          0.35        8.116     46.800      719.353        69.358    -11.636        5.681      20.576
       8          0.40        7.788     54.000      662.372        80.028    -13.575        6.555      19.110
       9          0.45        7.396     61.200      597.432        90.698    -15.472        7.429      17.421
      10          0.50        6.931     68.400      524.710       101.369    -17.326        8.303      15.512
      11          0.55        6.396     73.512      446.850       108.945    -18.550        9.177      13.424
      12          0.60        5.792     76.536      366.438       113.426    -19.158       10.051      11.229
      13          0.65        5.095     79.560      283.532       117.908    -19.752       10.925       8.961
      14          0.70        4.260     82.584      198.193       122.389    -20.332       11.799       6.618
      15          0.75        3.181     85.608      110.491       126.871    -20.895       12.673       4.190
      16          0.80        1.372     58.632       20.573       131.353    -21.422       13.547       1.577
```

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```
                                                  CUBE
SIDE   =    2.000
WEIGHT =    702.8  LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.10


  IMPACT VELOCITY EQUALS 15.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

       0.61  0.72  1.40  1.90  1.88  1.74  1.55  1.60


              CONDITIONS AT THE END OF SECTION                        WORK DONE IN SECTION - FOOT POUNDS

      ITERATION PENETRATION     VELOCITY   SHEAR      BODY ENERGY      STATIC     SEDIMENT      BUOYANT   FORM DRAG
       SECTION      FEET         FT/SEC  STRENGTH PSF    FT-LBS        FORCES     INERTIA       FORCES    FORCES

          1          0.05        13.390      4.392     1958.113         6.509     466.510       0.437     60.925
          2          0.10        13.281     13.176     1926.263        19.527      -7.588       1.311     53.735
          3          0.15        13.134     21.960     1884.022        32.545     -10.064       2.185     52.710
          4          0.20        12.950     30.744     1831.620        45.563     -12.484       3.059     51.401
          5          0.25        12.728     39.528     1769.281        58.580     -14.952       3.933     49.813
          6          0.30        12.466     48.312     1697.225        71.598     -17.167       4.807     47.953
          7          0.35        12.163     57.096     1615.667        84.616     -19.430       5.681     45.827
          8          0.40        11.816     65.880     1524.818        97.634     -21.644       6.555     43.441
          9          0.45        11.422     74.664     1424.883       110.652     -23.809       7.429     40.800
         10          0.50        10.977     83.448     1316.063       123.670     -25.926       8.303     37.910
         11          0.55        10.494     88.632     1202.215       131.353     -26.981       9.177     34.836
         12          0.60         9.988     90.216     1089.498       133.700     -26.997      10.051     31.700
         13          0.65         9.454     91.800      976.113       136.048     -27.013      10.925     28.562
         14          0.70         8.887     93.384      862.663       138.395     -27.029      11.799     25.421
         15          0.75         8.282     94.968      749.150       140.743     -27.044      12.673     22.278
         16          0.80         7.629     96.552      635.576       143.090     -27.058      13.547     19.132
         17          0.85         6.913     98.136      521.943       145.438     -27.072      14.421     15.983
         18          0.90         6.114     99.720      408.256       147.785     -27.085      15.295     12.829
         19          0.95         5.193    101.304      294.521       150.133     -27.097      16.169      9.667
         20          1.00         4.068    102.888      180.751       152.480     -27.105      17.043      6.489
         21          1.05         2.386    108.576       62.157       160.909     -28.254      17.917      3.159
```

```
                                                        CUBE
      SIDE   =     2.000
      WEIGHT =    702.8  LBS
      BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
      DRAG COEFFICIENT =  1.10


        IMPACT VELOCITY EQUALS 20.0

      SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
            0.75   0.95   0.95   1.30   2.40   2.87   2.91   3.04


                     CONDITIONS AT THE END OF SECTION
                                                                        WORK DONE IN SECTION - FOOT POUNDS
               ITERATION PENETRATION     VELOCITY   SHEAR        BODY ENERGY
                SECTION      FEET         FT/SEC  STRENGTH PSF     FT-LBS        STATIC      SEDIMENT       BUOYANT     FORM DRAG
                                                                                 FORCES      INERTIA        FORCES      FORCES

                   1         0.05         17.805     5.400      3462.389         9.003      824.897         0.437      108.038
                   2         0.10         17.628    16.200      3393.711        24.008      -16.362         1.311       94.845
                   3         0.15         17.417    27.000      3313.068        40.014      -19.213         2.185       92.779
                   4         0.20         17.173    37.800      3220.730        56.020      -21.999         3.059       90.386
                   5         0.25         16.894    43.600      3116.951        72.025      -24.725         3.933       87.673
                   6         0.30         16.579    59.400      3001.984        88.031      -27.390         4.807       84.646
                   7         0.35         16.228    70.200      2876.078       104.036      -29.996         5.681       81.313
                   8         0.40         15.838    81.000      2739.480       120.042      -32.544         6.555       77.680
                   9         0.45         15.407    91.800      2592.420       136.048      -35.036         7.429       73.755
                  10         0.50         14.932   102.600      2435.131       152.053      -37.474         8.303       69.543
                  11         0.55         14.425   109.440      2272.523       162.190      -38.740         9.177       65.115
                  12         0.60         13.898   112.320      2109.402       166.458      -38.963        10.051       60.608
                  13         0.65         13.349   115.200      1945.782       170.726      -38.982        10.925       56.086
                  14         0.70         12.772   118.080      1781.672       174.995      -39.099        11.799       51.551
                  15         0.75         12.168   120.960      1617.094       179.263      -39.212        12.673       47.001
                  16         0.80         11.530   123.840      1452.028       183.531      -39.324        13.547       42.438
                  17         0.85         10.853   126.720      1286.516       187.799      -39.432        14.421       37.861
                  18         0.90         10.129   129.600      1120.558       192.067      -39.538        15.295       33.271
                  19         0.95          9.347   132.480       954.165       196.335      -39.642        16.169       28.667
                  20         1.00          8.491   135.360       787.349       200.604      -39.743        17.043       24.049
                  21         1.05          7.546   136.800       621.826       202.738      -39.435        17.917       19.439
                  22         1.10          6.485   136.800       459.277       202.738      -38.727        18.791       14.884
                  23         1.15          5.238   136.800       299.646       202.738      -38.031        19.665       10.395
                  24         1.20          3.617   136.800       142.910       202.738      -37.342        20.539        5.938
 CORE USAGE      OBJECT CODE=     8032 BYTES,ARRAY AREA=     4200 BYTES,TOTAL AREA AVAILABLE=   43104  BYTES
 COMPILE TIME=     0.69 SEC,EXECUTION TIME=     0.66 SEC,  WATFIV - VERSION 1 LEVEL 1 JANUARY  1970    DATE=  70/281
```

APPENDIX G: COMPUTATION OF THE PENETRATION OF A RECTANGULAR PARALLELEPIPED

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A RECTANGLE
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX      INCREMENT SIZE
C
C BWD     BULK WET DENSITY OF SEDIMENT
C
C BMASS   OBJECT MASS
C
C AMASS() ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( ) PROJECTED AREA FOR SECTION ( )
C
C CNC     BEARING CAPACITY COEFFICIENT
C
C VOL( )  VOLUME OF SECTION ( )
C
C CFOOT   BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OR AREA
C
C XXX     DEPTH OF PENETRATION
C
C SVOL( ) SUM OF VOLUMES TO SECTION INDICATED
C
C V( )    VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )   WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT      WEIGHT OF OBJECT
C
C G       ACCELERATION OF GRAVITY
C
C SPS     SHEAR STRENGTH OF SEDIMENT
C
C DIM     DIMENSIONS OF THE RECTANGLE BASE
C
C WDRAG   WORK DONE BY DRAG FORCES
C
C WB( )   WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
```

```
C
C US( )   WORK TO SUBMERGE SECTION ( )
C
C SUMSUB()WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )    KINETIC ENERGY OF BODY AT SECTION( )
C
C
      DIMENSION AREA(500),VOL(500),AMASS(500),DMASS(500),SVOL(500),WS(50
     20),WB(500),WBSUB(500),US(500),SUMSUB(500),E(500),V(500)
      DATA PI/3.141593/,G/32.1725/,AREA/500*0.0/,VOL/500*0.0/,AMASS/500*
     20.0/,DMASS/500*0.0/,SVOL/500*0.0/,WS/500*0.0/,WB/500*0.0/,WBSUB/50
     30*0.0/,US/500*0.0/,SUMSUB/500*0.0/,E/500*0.0/,V/500*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT RECTANGLE
      DIM1=2.0
      DIM2=3.0
      WT=1014.75
      BWD=87.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C
C     FOR A RECTANGLE USE A COEFFICIENT OF DRAG EQUAL TO 1.0
      CD=1.0
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF RECTANGLE
      Y=DX/2.
      YMAX=DIM1
      Z=DIM1/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
      AREA(1)=DIM1*DIM2
      DO 100 I=2,N
      AREA(I)=AREA(1)
  100 CONTINUE
```

```
C
C     FOR THIS ANALYSIS THE AREA IS CONSTANT FOR THE REMAINING
C     PENETRATION, THEREFORE SET THE SUCCEEDING AREAS AS FOLLOWS
      DO 200 I=N,100
      AREA(I)=AREA(N)
C     PRINT,AREA(I)
  200 CONTINUE
C
C
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C     CHECK VOLUME CALCULATIONS
      HAFVOL=DIM1**2*DIM2
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
C     PRINT,CVOL,HAFVOL,ERROR
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE THF RECTANGLE BY USING ONE HALF OF AN ELLIPTICAL PLATE
C     WITH THE SAME AREA AND RATIO OF MAXIMUM AND MINIMUM DIMENSIONS
C     AS THE RECTANGLE.
C     AMASS BECOMES CONSTANT WHEN THE MAXIMUM AREA HAS BEEN REACHED
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION
C     SINCE SEPARATION OCCURS AT IMPACT AMASS REMAINS CONSTANT AND THERE
C     IS NO CONTRIBUTION FROM THE DISPLACED MASS.
C
      K=N+1
      DO 400 I=2,K
C     INTEGERS TRUNCATE SO THERE IS AN APPROXIMATION HERE IN THE NUMBER
C     OF ITERATIONS TAKEN
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
      EK=.51
C     THE ELLIPSE DIMENSIONS ARE
      A=SQRT(DIM2**2/PI)
      B=A/1.5
```

```
      REA=PI*A*B
C     PRINT,A,B,REA
C
      AMASS(I-1)=EK*(2./3.)*BWD*PI*A**2*B
  400 CONTINUE
C
C     AMASS REMAINS THE SAME AFTER THE MAX AREA
C
      DO 450 I=N,100
      AMASS(I)=AMASS(N)
C     PRINT,AMASS(N)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
C     PRINT,DMASS(N)
  500 CONTINUE
C
C
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,100
      WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY
C
      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
```

```
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
C     PRINT,WB(I)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
C     PRINT,CWB
C
C     ACTUAL WORK BY INTEGRATION IS
C
      X=N*DX
      AWB=(GAMMA)*DIM1*DIM2*X**2/2.
C     PRINT,AWB,X
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) DIM1,DIM2,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      E(1)=BMASS*VO**2/2.
```

```
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
      SLOPE1=SS05/.5
      BINT1=0.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE RECTANGLE TAKE THE DEPTH FOR THE SHEAR STRENGTH TO BE
C     PENETRATION DEPTH
      DEPTH=I*DX-Y
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
      IF(DEPTH.LE..5) GO TO 1
C
```

```
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
C
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
```

```
C       APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C       FIRST TIME OVER THE SECTION, AS DONE ABOVE
        VAVG=(V(I)+V(I+1))/2.
        IF(I.EQ.1) VAVG=(V0+V(I+1))/2.
        WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
        VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
       2S(I))
        IF (VELOSQ.LE.0.0)GO TO 1000
        V(I+1)=SQRT(VELOSQ)
C
C       CALCULATE E AT NEXT SECTION
        E(I+1)=BMASS*V(I+1)**2/2.
C
C       CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
        EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C       COMPUTE PENETRATION DEPTH
        XXX=I*DX
C
C       PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C       SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C       WORK DONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C       AND DRAG
C
        WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000   CONTINUE
 1000   CONTINUE
 2050   FORMAT(I5)
 2060   FORMAT(' ',I3)
 2100   FORMAT(F5.1,8F5.2)
 2200   FORMAT('1',60X,'RECTANGLE'//9X,'WIDTH = ',F7.2,'FEET'/9X,'LENGTH
       2= ',F7.2,'FEET'/9X,'WEIGHT = ',F7.2,' LBS'/9X,'BULK WET DENSITY =
       3',F5.2,' SLUGS PER CUBIC FOOT'/9X,'DRAG COEFFICIENT = ',F5.2///)
 2300   FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
       2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500   FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
       2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
       3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
       4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
       5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
       6ORCES'//)
 2600   FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
        STOP
        END
```

```
IMPACT VELOCITY EQUALS  0.0                                RECTANGLE

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE  WIDTH =      2.00FEET
      0.50  0.71  1.04  1.34  1.74  2.12  2.78  2.87             LENGTH  =      3.00FEET
                                                                  WEIGHT = 1014.75 LBS
                                                                  BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
                                                                  DRAG COEFFICIENT =  1.00
                CONDITIONS AT THE END OF SECTION
                                                                     WORK DONE IN SECTION - FOOT POUNDS
 ITERATION PENETRATION     VELOCITY   SHEAR      BODY ENERGY
  SECTION     FEET          FT/SEC  STRENGTH PSF    FT-LBS        STATIC     SEDIMENT      BUOYANT     FORM DRAG
                                                                  FORCES     INERTIA       FORCES      FORCES
    1          0.05         1.431      3.600       32.272
    2          0.10         1.790     10.800       50.536          8.003      9.598        0.656        0.210
    3          0.15         1.871     18.000       55.213         24.008      5.432        1.967        1.066
    4          0.20         1.719     25.200       46.552         40.014      1.391        3.278        1.379
    5          0.25         1.257     32.400       24.923         56.020     -2.567        4.589        1.327
                                                                  72.025     -6.441        5.900        0.913



IMPACT VELOCITY EQUALS  5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.35  1.02  1.37  2.68  2.99  3.02  2.95  2.77


                CONDITIONS AT THE END OF SECTION
                                                                     WORK DONE IN SECTION - FOOT POUNDS
 ITERATION PENETRATION     VELOCITY   SHEAR      BODY ENERGY
  SECTION     FEET          FT/SEC  STRENGTH PSF    FT-LBS        STATIC     SEDIMENT      BUOYANT     FORM DRAG
                                                                  FORCES     INERTIA       FORCES      FORCES
    1          0.05         4.581      2.520      330.886
    2          0.10         4.702      7.560      348.690          5.602     98.405        0.656        9.449
    3          0.15         4.755     12.600      356.588         16.806      5.295        1.967        8.865
    4          0.20         4.743     17.640      354.778         28.010      2.349        3.278        9.203
    5          0.25         4.667     22.680      343.453         39.214     -0.539        4.589        9.283
    6          0.30         4.524     27.720      322.804         50.418     -3.368        5.900        9.112
    7          0.35         4.310     32.760      293.019         61.622     -6.141        7.211        8.694
    8          0.40         4.015     37.800      254.278         72.825     -8.858        8.522        8.033
    9          0.45         3.621     42.840      206.765         84.029    -11.521        9.833        7.136
   10          0.50         3.091     47.880      150.657         95.233    -14.130       11.144        6.004
   11          0.55         2.284     55.224       82.237        106.437    -16.686       12.455        4.639
                                                                 122.763    -20.348       13.766        2.977
```

```
                                                    RECTANGLE
WIDTH =     2.COFFET
LENGTH  =     3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.00


 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.51  0.68  0.71  1.17  1.74  2.07  1.95  3.13

            CONDITIONS AT THE END OF SECTION
                                                                   WORK DONE IN SECTION - FOOT POUNDS
    ITERATION PENETRATION    VELOCITY   SHEAR     BODY ENERGY
     SECTION     FEET         FT/SEC  STRENGTH PSF   FT-LBS        STATIC    SEDIMENT      BUOYANT    FORM DRAG
                                                                   FORCES    INERTIA       FORCES     FORCES
      1          0.05         8.795      3.672     1219.820         8.163    362.771        0.656      36.373
      2          0.10         8.774     11.016     1214.055        24.489     -1.714        1.967      31.761
      3          0.15         8.705     18.360     1194.046        40.814     -5.683        3.278      31.437
      4          0.20         8.587     25.704     1162.759        57.140     -9.572        4.589      30.767
      5          0.25         8.419     33.048     1117.755        73.466    -13.334        5.900      29.759
      6          0.30         8.199     40.392     1060.190        89.791    -17.120        7.211      28.420
      7          0.35         7.924     47.736      990.314       106.117    -20.781        8.522      26.755
      8          0.40         7.589     55.080      908.373       122.443    -24.269        9.833      24.771
      9          0.45         7.187     62.424      814.609       138.768    -27.885       11.144      22.473
     10          0.50         6.706     69.768      709.259       155.094    -31.331       12.455      19.869
     11          0.55         6.151     74.664      596.706       165.979    -33.473       13.766      17.018
     12          0.60         5.524     77.112      481.248       171.420    -34.337       15.077      14.034
     13          0.65         4.797     79.560      362.948       176.862    -35.182       16.388      10.970
     14          0.70         3.916     82.008      241.869       182.304    -36.009       17.699       7.821
     15          0.75         2.737     84.456      118.096       187.746    -36.810       19.010       4.564
```

```
                                                     RECTANGLE
WIDTH =      2.00FEET
LENGTH  =       3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.00


  IMPACT VELOCITY EQUALS 15.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
        0.38  0.69  0.69  1.56  2.00  2.75  2.80  2.96

                  CONDITIONS AT THE END OF SECTION
                                                                        WORK DONE IN SECTION - FOOT POUNDS
     ITERATION PENETRATION        VELOCITY    SHEAR     BODY ENERGY
      SECTION      FEET            FT/SEC  STRENGTH PSF    FT-LBS        STATIC      SEDIMENT      BUOYANT     FORM DRAG
                                                                         FORCES      INERTIA       FORCES      FORCES
        1          0.05           13.100        2.736    2706.221        6.082      804.823        0.656       81.305
        2          0.10           13.025        8.208    2675.613       18.246       -9.102        1.967       70.231
        3          0.15           12.927       13.680    2635.334       30.411      -11.979        3.278       69.306
        4          0.20           12.804       19.152    2585.572       42.575      -14.790        4.589       68.131
        5          0.25           12.657       24.624    2526.520       54.739      -17.562        5.900       66.711
        6          0.30           12.485       30.096    2458.361       66.903      -20.270        7.211       65.051
        7          0.35           12.288       35.568    2381.277       79.068      -22.925        8.522       63.155
        8          0.40           12.065       41.040    2295.445       91.232      -25.526        9.833       61.029
        9          0.45           11.814       46.512    2201.039      103.396      -28.076       11.144       58.676
       10          0.50           11.535       51.984    2098.230      115.560      -30.575       12.455       56.101
       11          0.55           11.228       56.952    1989.045      126.604      -32.769       13.766       53.321
       12          0.60           10.894       61.416    1871.482      136.528      -34.666       15.077       50.360
       13          0.65           10.530       65.880    1749.668      146.451      -36.524       16.388       47.235
       14          0.70           10.134       70.344    1619.729      156.375      -38.346       17.699       43.948
       15          0.75            9.703       74.808    1484.737      166.298      -40.131       19.010       40.502
       16          0.80            9.231       79.272    1343.962      176.222      -41.881       20.321       36.900
       17          0.85            8.713       83.736    1197.372      186.145      -43.595       21.632       33.145
       18          0.90            8.141       88.200    1045.133      196.069      -45.276       22.943       29.240
       19          0.95            7.501       92.664     887.359      205.992      -46.922       24.254       25.186
       20          1.00            6.776       97.128     724.163      215.915      -48.534       25.565       20.986
       21          1.05            5.956       99.360     559.441      220.877      -48.988       26.876       16.692
       22          1.10            5.017       99.360     397.016      220.877      -48.305       28.187       12.402
       23          1.15            3.875       99.360     236.859      220.877      -47.630       29.498        8.149
       24          1.20            2.238       99.360      78.998      220.877      -46.948       30.809        3.860
```

```
                                                    RECTANGLE
WIDTH =      2.00FEET
LENGTH  =       3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.00


 IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.40  0.33  0.35  0.69  1.74  2.70  2.75  2.95


              CONDITIONS AT THE END OF SECTION
                                                                    WORK DONE IN SECTION - FOOT POUNDS

  ITERATION PENETRATION    VELOCITY   SHEAR    BODY ENERGY       STATIC      SEDIMENT      BUOYANT     FORM DRAG
   SECTION     FEET         FT/SEC  STRENGTH PSF   FT-LBS        FORCES      INERTIA       FORCES      FORCES

      1        0.05        13.099       2.880   2705.977         6.402      804.751        0.656       81.302
      2        0.10        13.023       8.640   2674.643        19.207       -9.318        1.967       70.215
      3        0.15        12.922      14.400   2633.160        32.011      -12.337        3.278       69.265
      4        0.20        12.795      20.160   2591.732        44.816      -15.294        4.589       68.053
      5        0.25        12.642      25.920   2520.559        57.620      -18.193        5.900       66.583
      6        0.30        12.464      31.680   2449.830        70.425      -21.034        7.211       64.862
      7        0.35        12.259      37.440   2369.740        83.229      -23.810        8.522       62.893
      8        0.40        12.025      43.200   2280.475        96.034      -26.547        9.833       60.683
      9        0.45        11.763      48.960   2182.215       108.838      -29.222       11.144       58.235
     10        0.50        11.471      54.720   2075.141       121.643      -31.843       12.455       55.554
     11        0.55        11.163      57.096   1965.170       126.924      -32.705       13.766       52.721
     12        0.60        10.855      56.088   1858.099       124.684      -31.843       15.077       49.888
     13        0.65        10.546      55.080   1753.870       122.443      -30.997       16.388       47.131
     14        0.70        10.236      54.072   1652.427       120.202      -30.169       17.699       44.447
     15        0.75         9.926      53.064   1553.714       117.961      -29.357       19.010       41.835
     16        0.80         9.614      52.056   1457.677       115.720      -28.561       20.321       39.293
     17        0.85         9.301      51.048   1364.263       113.480      -27.781       21.632       36.821
     18        0.90         8.986      50.040   1273.419       111.239      -27.017       22.943       34.416
     19        0.95         8.669      49.032   1185.093       108.998      -26.268       24.254       32.077
     20        1.00         8.349      48.024   1099.227       106.757      -25.534       25.565       29.804
     21        1.05         8.021      47.664   1014.701       105.957      -25.141       26.876       27.580
     22        1.10         7.681      47.952    930.360       106.597      -25.083       28.187       25.375
     23        1.15         7.325      48.240    846.211       107.237      -25.026       29.498       23.176
     24        1.20         6.952      48.528    762.250       107.878      -24.970       30.809       20.981
     25        1.25         6.559      48.816    678.473       108.518      -24.915       32.120       18.790
     26        1.30         6.142      49.104    594.877       109.158      -24.861       33.431       16.604
     27        1.35         5.695      49.392    511.459       109.798      -24.808       34.742       14.422
     28        1.40         5.211      49.680    428.217       110.439      -24.756       36.053       12.244
     29        1.45         4.678      49.968    345.146       111.079      -24.705       37.364       10.068
     30        1.50         4.079      50.256    262.247       111.719      -24.654       38.675        7.895
     31        1.55         3.337      52.848    175.617       117.481      -25.764       39.986        5.664
     32        1.60         2.273      57.744     81.452       128.364      -28.005       41.297        3.246
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                                                    RECTANGLE
WIDTH =      2.00FEET
LENGTH  =       3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY =  2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.00


  IMPACT VELOCITY EQUALS 20.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
        0.26  0.35  0.95  1.10  1.56  2.45  2.53  2.44


                   CONDITIONS AT THE END OF SECTION                   WORK DONE IN SECTION - FOOT POUNDS

     ITERATION PENETRATION     VELOCITY   SHEAR     BODY ENERGY      STATIC    SEDIMENT      BUOYANT    FORM DRAG
      SECTION     FEET          FT/SEC  STRENGTH PSF  FT-LBS         FORCES    INERTIA       FORCES     FORCES

         1        0.05         17.421      1.872    4786.410         4.161    1423.468       0.656      144.199
         2        0.10         17.298      5.616    4718.758        12.484     -20.120       1.967      124.039
         3        0.15         17.162      9.360    4645.102        20.807     -21.905       3.278      122.195
         4        0.20         17.015     13.104    4565.555        29.130     -23.657       4.589      120.196
         5        0.25         16.855     16.848    4480.246        37.453     -25.371       5.900      118.045
         6        0.30         16.633     20.592    4389.281        45.776     -27.053       7.211      115.745
         7        0.35         16.499     24.336    4292.773        54.099     -28.702       8.522      113.298
         8        0.40         16.302     28.080    4190.844        62.422     -30.314       9.833      110.708
         9        0.45         16.092     31.824    4083.592        70.745     -31.896      11.144      107.979
        10        0.50         15.868     35.568    3971.131        79.068     -33.446      12.455      105.111
        11        0.55         15.636     38.088    3855.639        84.670     -34.347      13.766      102.136
        12        0.60         15.398     39.384    3739.244        87.551     -34.615      15.077       99.110
        13        0.65         15.155     40.630    3621.971        90.432     -34.877      16.388       96.061
        14        0.70         14.906     41.976    3503.834        93.313     -35.133      17.699       92.989
        15        0.75         14.650     43.272    3384.852        96.194     -35.385      19.010       89.894
        16        0.80         14.389     44.568    3265.039        99.075     -35.632      20.321       86.778
        17        0.85         14.120     45.964    3144.416       101.956     -35.873      21.632       83.640
        18        0.90         13.845     47.160    3022.998       104.837     -36.109      22.943       80.481
        19        0.95         13.562     48.456    2900.799       107.718     -36.341      24.254       77.302
        20        1.00         13.272     49.752    2777.833       110.599     -36.569      25.565       74.102
        21        1.05         12.958     54.720    2647.896       121.642     -38.644      26.876       70.801
        22        1.10         12.603     63.360    2504.889       140.849     -42.531      28.187       67.237
        23        1.15         12.205     72.000    2349.072       160.056     -46.339      29.498       63.335
        24        1.20         11.759     80.640    2180.705       179.262     -50.072      30.809       59.101
        25        1.25         11.262     89.280    2000.039       198.469     -53.730      32.120       54.543
        26        1.30         10.705     97.920    1807.318       217.675     -57.315      33.431       49.664
        27        1.35         10.081    106.560    1602.784       236.882     -60.829      34.742       44.473
        28        1.40          9.377    115.200    1386.675       256.089     -64.270      36.053       38.974
        29        1.45          8.574    123.840    1159.224       275.296     -67.643      37.364       33.171
        30        1.50          7.641    132.480     920.662       294.502     -70.948      38.675       27.068
        31        1.55          6.551    137.880     676.715       306.507     -72.549      39.986       20.740
        32        1.60          5.240    140.040     433.003       311.309     -72.479      41.297       14.322
        33        1.65          3.467    142.200     189.591       316.110     -72.390      42.609        7.821
```

APPENDIX H: COMPUTATION OF THE PENETRATION OF A CONE

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A CONE
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX       INCREMENT SIZE
C
C BWD      BULK WET DENSITY OF SEDIMENT
C
C BMASS    OBJECT MASS
C
C AMASS()  ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( ) PROJECTED AREA FOR SECTION ( )
C
C CNC      BEARING CAPACITY COEFFICIENT
C
C VOL( )   VOLUME OF SECTION ( )
C
C CFOOT    BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX      DEPTH OF PENETRATION
C
C SVOL( ) SUM OF VOLUMES TO SECTION INDICATED
C
C V( )     VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )    WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT       WEIGHT OF OBJECT
C
C G        ACCELERATION OF GRAVITY
C
C SPS      SHEAR STRENGTH OF SEDIMENT
C
C RAD      RADIUS
C
C DIM      LENGTH OF CONE
C
C WDRAG    WORK DONE BY DRAG FORCES
C
C WB( )    WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
```

```
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )    WORK TO SUBMERGE SECTION ( )
C
C SUMSUB( )WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )     KINETIC ENERGY OF BODY AT SECTION( )
C
C
      DIMENSION AREA(500),VOL(500),AMASS(500),DMASS(500),SVOL(500),WS(50
     20),WB(500),WBSUB(500),US(500),SUMSUB(500),E(500),V(500)
      DATA PI/3.141593/,G/32.1725/,AREA/500*0.0/,VOL/500*0.0/,AMASS/500*
     20.0/,DMASS/500*0.0/,SVOL/500*0.0/,WS/500*0.0/,WB/500*0.0/,WBSUB/50
     30*0.0/,US/500*0.0/,SUMSUB/500*0.0/,E/500*0.0/,V/500*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT CONE
      RAD=35.375/24.
      DIM=5.50
      WT=1127.
      BWD=87.402/G
      CFOOT=1.
C     THE CONE'S ANGLE AT THE TIP IS 30 DEGREES
      CNC=4.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3
      COH=43.2
C
C     FOR A CONE USE A COEFFICIENT OF DRAG EQUAL TO 0.3
      CD=0.3
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE POINT OF A CONE
      Y=DX/2.
      YMAX=DIM
      Z=DIM/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
C     FIND HALF THE ANGLE AT THE TIP OF THE CONE
      ALFA=ATAN(RAD/DIM)
```

```
      RAA=TAN(ALFA)*(DX-Y)
      AREA(1)=PI*RAA**2
      DO 100 I=2,N
      RAA=TAN(ALFA)*(I*DX-Y)
      AREA(I)=PI*RAA**2
  100 CONTINUE
C
C     FOR THIS ANALYSIS AFTER THE AREA HAS BECOME A MAXIMUM IT WILL BE
C     CONSTANT FOR THE REMAINING PENETRATION THEREFORE SET SUCCEEDING
C     AREAS AS FOLLOWS
      DO 200 I=N,500
      AREA(I)=AREA(N)
  200 CONTINUE
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,500
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVOL=PI*RAD**2*DIM/3.
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
C     PRINT,CVOL,HAFVOL,ERROR
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE ADDED MASS BY USING ONE HALF OF A PROLATE ELLIPSOID.
C     AMASS BECOMES CONSTANT WHEN THE MAXIMUM AREA HAS BEEN REACHED.
C
      SUMVOL=0.0
      K=N+1
C     INTEGERS TRUNCATE SO THERE IS AN APPROXIMATION HERE IN THE NUMBER
C     OF ITERATIONS TAKEN
      DO 400 I=2,K
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
C     NOW ADDED MASS,DESIGNATE SOME NEW VARIABLES
      EK=0.095
      A=(I-1)*DX-Y
      B=TAN(ALFA)*A
```

```
      AMASS(I-1)=BWD*EK*(2./3.)*PI*A*B**2
C     ADD DISPLACED VOL AT THE SAME TIME
C
C     SUM THE VOLUMES BEFORE ADDING
C
      SUMVOL=SUMVOL+VOL(I-1)
C     SUMVOL AT END OF DO LOOP SHOULD EQUAL HAFVOL
C
      AMASS(I-1)=AMASS(I-1)+BWD*SUMVOL
  400 CONTINUE
C
C     CHECK ADDED MASS BY COMPARING LAST INCREMENT TO ONE HALF ELLIPSOID
C
      HAMAS=BWD*(PI*RAD**2*DIM*EK*(2./3.)+PI*RAD**2*DIM/3.)
      ERROR=HAMAS-AMASS(N)
C     PRINT,HAMAS,AMASS(N),ERROR
C
      DO 450 I=N,500
      AMASS(I)=AMASS(N)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
  500 CONTINUE
C
C     SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C
      CDMASS=DMASS(1)
      DO 550 I=2,N
      CDMASS=CDMASS+DMASS(I)
  550 CONTINUE
C     PRINT,CDMASS,AMASS(N)
C
C
C
C     FOR THE ORIGINAL PROGRAM CHECKOUT
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT OVER THE DEPTH
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,500
      WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
```

```
C     CALCULATE WORK DONE BY BUOYANCY
C
      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT.
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION.
C
      DO 760 I=N,500
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
      PRINT,CWB
C
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) RAD,DIM,WT,BWD,CD
```

```
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40,SS405,
     2SS500,SS505,SS600
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40,SS405,
     2SS500,SS505,SS600
      WRITE(6,2500)
C
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
      SLOPE1=SS05/.5
      BINT1=0.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
      SLOPE9=(SS405-SS40)/.5
      BINT9=-SLOPE9*4.0+SS40
C
      SLOPEA=(SS500-SS405)/.5
      BINTA=-SLOPEA*4.5+SS405
```

```
C
      SLOPEB=(SS505-SS500)/.5
      BINTB=-SLOPEB*5.0+SS500
C
      SLOPEC=(SS600-SS505)/.5
      BINTC=-SLOPEC*5.5+SS505
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,500
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE CONE TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE
C     PENETRATION DEPTH MINUS ONE HALF THE PENETRATION DEPTH
      DEPTH=I*DX-Y-(I*DX-Y)/2.
C     WHEN THE DEPTH OF PENETRATION EQUALS ONE HALF THE LENGTH OF THE
C     CONE THE DEPTH FOR SHEAR STRENGTHS EQUALS THE PENETRATION DEPTH
C     MINUS ONE HALF THE LENGTH
      IF((I*DX-Y).GT.DIM) DEPTH=I*DX-Y-DIM/2.
C
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
      IF(DEPTH.LE..5) GO TO 1
C
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
      IF((DEPTH.LE.4.5).AND.(DEPTH.GT.4.0)) GO TO 9
      IF((DEPTH.LE.5.0).AND.(DEPTH.GT.4.5)) GO TO 11
      IF((DEPTH.LE.5.5).AND.(DEPTH.GT.5.0)) GO TO 12
      IF((DEPTH.LE.6.0).AND.(DEPTH.GT.5.5)) GO TO 13
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.6.0) GO TO 14
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
```

```
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
    9 SSS=SLOPE9*DEPTH+BINT9
      GO TO 10
   11 SSS=SLOPEA*DEPTH+BINTA
      GO TO 10
   12 SSS=SLOPEB*DEPTH+BINTB
      GO TO 10
   13 SSS=SLOPEC*DEPTH+BINTC
      GO TO 10
   14 SSS=(SS500+SS505+SS600)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
C     APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C     FIRST TIME OVER THE SECTION, AS DONE ABOVE
      VAVG=(V(I)+V(I+1))/2.
      IF(I.EQ.1) VAVG=(V0+V(I+1))/2.
      WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
     2S(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
```

```
      V(I+1)=SQRT(VELOSQ)
C
C     CALCULATE E AT NEXT SECTION
      E(I+1)=BMASS*V(I+1)**2/2.
C
C     CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
      EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C     COMPUTE PENETRATION DEPTH
      XXX=I*DX
C
C     PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C     SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C     WORKDONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C     AND DRAG
C
      WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000 CONTINUE
 1000 CONTINUE
 2050 FORMAT(I5)
 2060 FORMAT(' ',I3)
 2100 FORMAT(F5.1,12F5.2)
 2200 FORMAT('1',60X,'CONE '//9X,'RADIUS = ',F7.3,' FEET'/9X,'LENGTH = '
     2,F7.3,' FEET'/9X,'WEIGHT = ',F7.1,' LBS'/9X,'BULK WET DENSITY =  '
     3,F5.2,' SLUGS PER CUBIC FOOT'/9X,'DRAG COEFFICIENT = ',F5.2///)
 2300 FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
     2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,12F6.2//)
 2500 FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
     2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
     3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
     4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
     5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
     6ORCES'//)
 2600 FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
      STOP
      END
```

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                                                        CONE
RADIUS =      1.474 FEET
LENGTH =      5.500 FEET
WEIGHT =   1127.0 LBS
BULK WET DENSITY =    2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


  IMPACT VELOCITY EQUALS  0.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
       0.48  0.69  1.10  1.38  1.86  2.50  2.31  2.52  2.81  2.65  2.50  2.80

                    CONDITIONS AT THE END OF SECTION
                                                                    WORK DONE IN SECTION - FOOT POUNDS
     ITERATION PENETRATION    VELOCITY   SHEAR       BODY ENERGY    STATIC     SEDIMENT    BUOYANT    FORM DRAG
      SECTION     FEET         FT/SEC  STRENGTH PSF    FT-LBS       FORCES     INERTIA     FORCES      FORCES

         1        0.05         1.794      1.728        56.350       0.000       0.000      0.000       0.000
         2        0.10         2.537      5.184       112.697       0.002       0.001      0.000       0.000
         3        0.15         3.107      8.640       169.035       0.007       0.004      0.001       0.001
         4        0.20         3.597     12.096       225.352       0.020       0.010      0.002       0.002
         5        0.25         4.010     15.552       281.632       0.042       0.020      0.004       0.003
         6        0.30         4.392     19.008       337.955       0.076       0.036      0.007       0.006
         7        0.35         4.743     22.464       393.998       0.126       0.058      0.011       0.010
         8        0.40         5.069     25.920       450.032       0.193       0.089      0.017       0.016
         9        0.45         5.375     29.376       505.925       0.281       0.128      0.025       0.023
        10        0.50         5.663     32.832       561.637       0.393       0.177      0.035       0.032
        11        0.55         5.936     36.288       617.128       0.530       0.237      0.048       0.043
        12        0.60         6.196     39.744       672.353       0.697       0.309      0.063       0.056
        13        0.65         6.444     43.200       727.260       0.895       0.395      0.080       0.072
        14        0.70         6.681     46.656       781.797       1.127       0.494      0.101       0.090
        15        0.75         6.908     50.112       835.904       1.397       0.608      0.126       0.112
        16        0.80         7.126     53.568       889.520       1.706       0.738      0.153       0.136
        17        0.85         7.336     57.024       942.578       2.058       0.885      0.185       0.164
        18        0.90         7.537     60.480       995.009       2.455       1.048      0.221       0.195
        19        0.95         7.731     63.936      1046.740       2.901       1.228      0.261       0.229
        20        1.00         7.917     67.392      1097.693       3.397       1.427      0.305       0.268
        21        1.05         8.095     69.876      1147.842       3.893       1.644      0.354       0.310
        22        1.10         8.267     71.388      1197.172       4.374       1.881      0.409       0.356
        23        1.15         8.433     72.900      1245.620       4.892       2.136      0.468       0.406
        24        1.20         8.592     74.412      1293.118       5.447       2.410      0.534       0.460
        25        1.25         8.745     75.924      1339.600       6.041       2.703      0.605       0.519
        26        1.30         8.892     77.436      1384.906       6.675       3.015      0.682       0.581
        27        1.35         9.033     78.948      1429.237       7.349       3.346      0.765       0.649
        28        1.40         9.168     80.460      1472.253       8.066       3.694      0.855       0.720
        29        1.45         9.297     81.972      1513.970       8.826       4.058      0.952       0.796
        30        1.50         9.420     83.484      1554.318       9.630       4.439      1.055       0.876
        31        1.55         9.537     84.996      1593.225      10.481       4.835      1.166       0.961
        32        1.60         9.649     86.508      1630.616      11.378       5.245      1.285       1.050
        33        1.65         9.754     88.020      1666.421      12.324       5.667      1.411       1.143
```

34	1.70	9.854	89.532	1700.565	13.319	6.100	1.545	1.240
35	1.75	9.947	91.044	1732.980	14.365	6.542	1.688	1.341
36	1.80	10.034	92.556	1763.593	15.462	6.990	1.839	1.446
37	1.85	10.116	94.068	1792.334	16.612	7.443	1.999	1.555
38	1.90	10.191	95.580	1819.134	17.817	7.898	2.167	1.667
39	1.95	10.260	97.092	1843.927	19.077	8.353	2.345	1.782
40	2.00	10.323	98.604	1866.646	20.393	8.804	2.533	1.900
41	2.05	10.380	100.836	1887.080	21.924	9.240	2.730	2.021
42	2.10	10.429	103.788	1905.002	23.694	9.652	2.937	2.144
43	2.15	10.471	106.740	1920.326	25.557	10.046	3.155	2.268
44	2.20	10.505	109.692	1932.971	27.514	10.415	3.383	2.394
45	2.25	10.532	112.644	1942.855	29.569	10.756	3.621	2.520
46	2.30	10.551	115.596	1949.962	31.722	11.063	3.871	2.646
47	2.35	10.562	118.548	1954.039	33.978	11.331	4.132	2.771
48	2.40	10.566	121.500	1955.19[illegible]	36.338	11.554	4.404	2.896
49	2.45	10.560	124.452	1953.304	38.805	11.728	4.688	3.018
50	2.50	10.547	127.404	1947.305	41.380	11.846	4.984	3.139
51	2.55	10.525	130.356	1939.136	44.067	11.902	5.292	3.256
52	2.60	10.494	133.308	1928.744	46.867	11.891	5.613	3.369
53	2.65	10.454	136.260	1914.091	49.784	11.805	5.946	3.478
54	2.70	10.405	139.212	1896.099	52.819	11.638	6.292	3.581
55	2.75	10.346	142.164	1874.759	55.974	11.385	6.652	3.678
56	2.80	10.277	145.116	1850.075	59.252	11.038	7.025	3.768
57	2.85	10.199	148.068	1821.868	62.656	10.590	7.411	3.849
58	2.90	10.110	151.020	1790.261	66.187	10.036	7.812	3.922
59	2.95	10.011	153.972	1755.185	69.848	9.367	8.226	3.985
60	3.00	9.900	156.924	1716.621	73.642	8.578	8.655	4.036
61	3.05	9.778	159.408	[illegible]	77.343	7.701	9.099	4.077
62	3.10	9.646	161.424	1629.768	80.932	6.738	9.558	4.105
63	3.15	9.503	163.440	1581.687	84.629	5.650	10.032	4.120
64	3.20	9.348	165.456	1530.527	88.436	4.431	10.521	4.121
65	3.25	9.181	167.472	1475.310	92.356	3.077	11.026	4.108
66	3.30	9.001	169.488	1416.064	96.389	1.581	11.546	4.080
67	3.35	8.808	171.504	1352.821	100.535	-0.060	12.083	4.035
68	3.40	8.601	173.520	1295.615	104.799	-1.853	12.637	3.972
69	3.45	8.378	175.536	1229.486	109.182	-3.801	13.207	3.891
70	3.50	8.140	177.552	1160.477	113.683	-5.909	13.793	3.791
71	3.55	7.884	179.568	[illegible]	118.307	-8.182	14.397	3.671
72	3.60	7.609	181.584	1014.005	123.053	-10.624	15.019	3.530
73	3.65	7.313	183.600	936.643	127.924	-13.238	15.658	3.367
74	3.70	6.993	185.616	856.005	132.920	-16.029	16.315	3.181
75	3.75	6.647	187.632	773.949	138.045	-19.000	16.990	2.971
76	3.80	6.271	189.648	688.734	143.299	-22.155	17.683	2.737
77	3.85	5.858	191.664	601.024	148.684	-25.497	18.395	2.477
78	3.90	5.401	193.680	510.884	154.202	-29.028	19.126	2.191
79	3.95	4.887	195.696	418.379	159.854	-32.753	19.875	1.877
80	4.00	4.298	197.712	323.590	165.641	-36.672	20.645	1.535
81	4.05	3.593	200.448	226.139	172.185	-40.989	21.434	1.161
82	4.10	2.679	203.904	125.700	179.532	-45.737	22.242	0.752
83	4.15	1.129	207.360	22.342	187.083	-50.731	23.071	0.284

```
                                                   CONE
RADIUS =     1.474 FEET
LENGTH =     5.500 FEET
WEIGHT =   1127.0 LBS
BULK WET DENSITY =    2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


  IMPACT VELOCITY EQUALS  5.0

 SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
           0.65  0.63  0.68  1.80  2.32  2.56  2.51  2.26  1.89  1.64  1.60  1.79

                    CONDITIONS AT THE END OF SECTION
                                                                        WORK DONE IN SECTION - FOOT POUNDS
        ITERATION PENETRATION     VELOCITY   SHEAR    BODY ENERGY      STATIC      SEDIMENT       BUOYANT     FORM DRAG
         SECTION     FEET          FT/SEC  STRENGTH PSF  FT-LBS        FORCES      INERTIA        FORCES      FORCES

            1        0.05           5.312      2.340     494.222        0.000        0.000         0.000        0.000
            2        0.10           5.607      7.020     550.565        0.002        0.003         0.000        0.001
            3        0.15           5.886     11.700     606.891        0.010        0.011         0.001        0.002
            4        0.20           6.153     16.380     663.183        0.027        0.023         0.002        0.005
            5        0.25           6.409     21.060     719.420        0.057        0.042         0.004        0.009
            6        0.30           6.654     25.740     775.575        0.103        0.069         0.007        0.015
            7        0.35           6.891     30.420     831.615        0.170        0.105         0.011        0.022
            8        0.40           7.118     35.100     887.503        0.262        0.151         0.017        0.032
            9        0.45           7.338     39.780     943.194        0.381        0.208         0.025        0.043
           10        0.50           7.551     44.460     998.641        0.532        0.278         0.035        0.057
           11        0.55           7.757     49.140    1053.790        0.718        0.360         0.048        0.074
           12        0.60           7.956     53.820    1108.582        0.943        0.457         0.063        0.094
           13        0.65           8.149     58.500    1162.955        1.212        0.569         0.080        0.116
           14        0.70           8.335     63.180    1216.837        1.526        0.697         0.101        0.142
           15        0.75           8.516     67.860    1270.157        1.891        0.841         0.126        0.172
           16        0.80           8.691     72.540    1322.835        2.310        1.003         0.153        0.204
           17        0.85           8.860     77.220    1374.789        2.787        1.183         0.185        0.241
           18        0.90           9.023     81.900    1425.930        3.325        1.382         0.221        0.291
           19        0.95           9.180     86.580    1476.167        3.928        1.599         0.261        0.326
           20        1.00           9.332     91.260    1525.402        4.600        1.835         0.305        0.374
           21        1.05           9.479     93.528    1573.669        5.210        2.091         0.354        0.427
           22        1.10           9.620     93.384    1621.034        5.722        2.369         0.409        0.485
           23        1.15           9.757     93.240    1667.445        6.257        2.667         0.468        0.546
           24        1.20           9.889     93.096    1712.850        6.915        2.985         0.534        0.613
           25        1.25          10.016     92.952    1757.193        7.396        3.323         0.605        0.683
           26        1.30          10.139     92.808    1800.421        8.000        3.681         0.682        0.759
           27        1.35          10.256     92.664    1842.480        8.626        4.060         0.765        0.839
           28        1.40          10.369     92.520    1883.320        9.275        4.457         0.855        0.925
           29        1.45          10.478     92.376    1922.884        9.946        4.873         0.952        1.015
           30        1.50          10.582     92.232    1961.123       10.640        5.307         1.055        1.109
           31        1.55          10.680     92.088    1997.983       11.355        5.758         1.166        1.209
           32        1.60          10.775     91.944    2033.417       12.093        6.225         1.285        1.313
           33        1.65          10.864     91.800    2067.373       12.853        6.707         1.411        1.422
```

34	1.70	10.949	91.656	2099.803	13.635	7.203	1.545	1.535
35	1.75	11.029	91.512	2130.662	14.438	7.711	1.688	1.653
36	1.80	11.105	91.368	2159.904	15.263	8.229	1.839	1.775
37	1.85	11.176	91.224	2187.486	16.110	8.757	1.999	1.901
38	1.90	11.241	91.080	2213.365	16.978	9.291	2.167	2.031
39	1.95	11.303	90.936	2237.504	17.867	9.832	2.345	2.165
40	2.00	11.359	90.792	2259.963	18.778	10.375	2.533	2.303
41	2.05	11.410	90.900	2280.357	19.764	10.916	2.730	2.445
42	2.10	11.457	91.260	2298.895	20.834	11.451	2.937	2.589
43	2.15	11.499	91.620	2315.436	21.937	11.980	3.155	2.736
44	2.20	11.534	91.980	2329.343	23.071	12.500	3.383	2.886
45	2.25	11.564	92.340	2342.385	24.239	13.009	3.621	3.037
46	2.30	11.590	92.700	2352.729	25.439	13.502	3.871	3.191
47	2.35	11.610	93.060	2360.947	26.673	13.979	4.132	3.346
48	2.40	11.625	93.420	2367.016	27.940	14.434	4.404	3.502
49	2.45	11.635	93.780	2370.910	29.241	14.864	4.688	3.659
50	2.50	11.639	94.140	2372.615	30.576	15.267	4.984	3.816
51	2.55	11.639	94.500	2372.115	31.946	15.639	5.292	3.973
52	2.60	11.631	94.860	2369.395	33.350	15.976	5.613	4.129
53	2.65	11.619	95.220	2364.447	34.789	16.275	5.946	4.284
54	2.70	11.601	95.580	2357.268	36.264	16.533	6.292	4.438
55	2.75	11.578	95.940	2347.855	37.774	16.746	6.652	4.589
56	2.80	11.549	96.300	2336.211	39.320	16.910	7.025	4.738
57	2.85	11.515	96.660	2322.340	40.902	17.023	7.411	4.883
58	2.90	11.475	97.020	2306.220	42.521	17.080	7.812	5.025
59	2.95	11.429	97.380	2287.955	44.176	17.079	8.226	5.163
60	3.00	11.378	97.740	2267.471	45.868	17.014	8.655	5.296
61	3.05	11.317	101.952	2242.264	49.456	16.567	9.099	5.422
62	3.10	11.242	110.016	2213.711	55.158	15.650	9.558	5.536
63	3.15	11.153	118.080	2179.717	61.142	14.533	10.032	5.635
64	3.20	11.049	126.144	2138.193	67.424	13.204	10.521	5.717
65	3.25	10.929	134.200	2092.080	74.012	11.651	11.026	5.780
66	3.30	10.793	142.272	2040.291	80.910	9.857	11.546	5.823
67	3.35	10.640	150.336	1982.774	88.127	7.813	12.083	5.843
68	3.40	10.469	158.400	1919.476	95.667	5.503	12.637	5.840
69	3.45	10.278	166.464	1850.354	103.539	2.914	13.207	5.810
70	3.50	10.068	174.528	1775.376	111.747	0.034	13.793	5.752
71	3.55	9.835	182.592	1694.516	120.299	-3.152	14.397	5.665
72	3.60	9.581	190.656	1607.758	129.200	-6.655	15.019	5.545
73	3.65	9.301	198.720	1515.090	138.458	-10.491	15.658	5.391
74	3.70	8.993	206.784	1416.515	148.079	-14.669	16.315	5.201
75	3.75	8.655	214.848	1312.037	158.069	-19.205	16.990	4.974
76	3.80	8.283	222.912	1201.673	168.433	-24.109	17.683	4.705
77	3.85	7.872	230.976	1085.447	179.180	-29.393	18.395	4.395
78	3.90	7.416	239.040	963.385	190.316	-35.071	19.126	4.040
79	3.95	6.907	247.104	835.528	201.846	-41.153	19.875	3.638
80	4.00	6.331	255.168	701.917	213.777	-47.650	20.645	3.187
81	4.05	5.674	261.072	563.861	224.260	-53.975	21.434	2.687
82	4.10	4.913	264.916	422.698	233.163	-60.036	22.242	2.142
83	4.15	3.988	268.560	278.520	242.298	-66.393	23.071	1.552
84	4.20	2.739	272.304	131.420	251.668	-73.047	23.920	0.908

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                                                  CONE
RADIUS =    1.474 FEET
LENGTH =    5.500 FEET
WEIGHT =  1127.0 LBS
BULK WET DENSITY =   2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


 IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

      0.30  0.23  0.47  2.05  2.53  3.31  3.81  3.95  3.73  3.35  3.22  3.12


                  CONDITIONS AT THE END OF SECTION                    WORK DONE IN SECTION - FOOT POUNDS

  ITERATION PENETRATION    VELOCITY   SHEAR        BODY ENERGY     STATIC     SEDIMENT     BUOYANT    FORM DRAG
   SECTION      FEET        FT/SEC   STRENGTH PSF    FT-LBS        FORCES     INERTIA      FORCES     FORCES

      1         0.05       10.160       1.000      1807.843        0.000      0.001        0.000       0.000
      2         0.10       10.317       3.240      1864.178        0.001      0.010        0.000       0.003
      3         0.15       10.471       5.400      1920.484        0.004      0.031        0.001       0.008
      4         0.20       10.624       7.560      1976.740        0.012      0.063        0.002       0.016
      5         0.25       10.773       9.720      2032.922        0.026      0.109        0.004       0.027
      6         0.30       10.921      11.880      2088.036        0.048      0.170        0.007       0.041
      7         0.35       11.066      14.040      2144.959        0.079      0.246        0.011       0.059
      8         0.40       11.210      16.200      2200.748        0.121      0.340        0.017       0.080
      9         0.45       11.350      18.360      2255.929        0.176      0.451        0.025       0.106
     10         0.50       11.482      20.520      2311.689        0.245      0.581        0.035       0.135
     11         0.55       11.624      22.680      2366.758        0.331      0.731        0.048       0.169
     12         0.60       11.759      24.840      2421.493        0.435      0.903        0.063       0.208
     13         0.65       11.889      27.000      2475.850        0.559      1.096        0.080       0.251
     14         0.70       12.013      29.160      2529.791        0.704      1.312        0.101       0.299
     15         0.75       12.144      31.320      2583.234        0.873      1.552        0.126       0.353
     16         0.80       12.269      33.480      2636.135        1.066      1.817        0.153       0.411
     17         0.85       12.389      35.640      2688.620        1.286      2.107        0.185       0.476
     18         0.90       12.503      37.800      2740.053        1.535      2.422        0.221       0.545
     19         0.95       12.623      39.960      2790.945        1.813      2.764        0.261       0.621
     20         1.00       12.736      42.120      2841.029        2.123      3.133        0.305       0.703
     21         1.05       12.846      42.948      2890.313        2.392      3.529        0.354       0.790
     22         1.10       12.953      42.444      2938.816        2.601      3.953        0.409       0.884
     23         1.15       13.058      41.940      2986.492        2.814      4.406        0.468       0.984
     24         1.20       13.160      41.436      3033.295        3.033      4.887        0.534       1.091
     25         1.25       13.259      40.932      3079.182        3.257      5.396        0.605       1.204
     26         1.30       13.355      40.428      3124.107        3.485      5.934        0.682       1.324
     27         1.35       13.449      39.924      3168.025        3.716      6.499        0.765       1.450
     28         1.40       13.540      39.420      3210.893        3.952      7.093        0.855       1.583
     29         1.45       13.627      38.916      3252.662        4.190      7.715        0.952       1.723
     30         1.50       13.712      38.412      3293.291        4.431      8.364        1.055       1.870
     31         1.55       13.794      37.908      3332.738        4.674      9.039        1.166       2.023
     32         1.60       13.873      37.404      3370.957        4.920      9.741        1.285       2.183
     33         1.65       13.949      36.900      3407.912        5.166     10.467        1.411       2.350
     34         1.70       14.022      36.396      3443.559        5.414     11.218        1.545       2.524
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35	1.75	14.091	35.892	3477.859	5.663	11.992	1.688	2.704
36	1.80	14.153	35.388	3510.777	5.912	12.789	1.839	2.891
37	1.85	14.221	34.884	3542.277	6.160	13.605	1.999	3.084
38	1.90	14.281	34.380	3572.324	6.409	14.442	2.167	3.284
39	1.95	14.338	33.876	3600.887	6.656	15.296	2.345	3.490
40	2.00	14.392	33.372	3627.934	6.902	16.167	2.533	3.702
41	2.05	14.442	33.934	3653.205	7.389	17.038	2.730	3.920
42	2.10	14.488	35.712	3676.418	8.153	17.901	2.937	4.144
43	2.15	14.529	37.440	3697.510	8.964	18.765	3.155	4.372
44	2.20	14.567	39.168	3716.420	9.825	19.627	3.383	4.605
45	2.25	14.599	40.896	3733.088	10.735	20.484	3.621	4.843
46	2.30	14.627	42.624	3747.451	11.697	21.330	3.871	5.084
47	2.35	14.651	44.352	3759.457	12.712	22.162	4.132	5.329
48	2.40	14.669	46.080	3769.059	13.782	22.977	4.404	5.577
49	2.45	14.683	47.808	3776.207	14.907	23.771	4.688	5.827
50	2.50	21.515	128.628	8107.480	41.778	46.177	4.984	13.085
51	2.55	21.443	132.012	8053.281	44.627	47.081	5.292	13.532
52	2.60	21.364	135.396	7994.531	47.502	47.885	5.613	13.975
53	2.65	21.280	138.780	7931.211	50.705	48.586	5.946	14.413
54	2.70	21.188	142.164	7863.293	53.938	49.170	6.292	14.844
55	2.75	21.090	145.548	7790.762	57.306	49.631	6.652	15.268
56	2.80	20.985	148.932	7713.613	60.810	49.962	7.025	15.682
57	2.85	20.874	152.316	7631.840	64.453	50.151	7.411	16.086
58	2.90	20.756	155.700	7545.449	68.238	50.191	7.812	16.479
59	2.95	20.630	159.084	7454.441	72.167	50.074	8.226	16.858
60	3.00	20.498	162.468	7358.879	76.244	49.788	8.655	17.223
61	3.05	20.357	167.724	7257.934	81.378	49.175	9.099	17.571
62	3.10	20.206	174.852	7151.016	87.664	48.185	9.558	17.898
63	3.15	20.046	181.980	7037.934	94.229	46.937	10.032	18.203
64	3.20	19.875	189.108	6918.750	101.078	45.428	10.521	18.483
65	3.25	19.694	196.236	6793.465	108.218	43.641	11.026	18.736
66	3.30	19.503	203.364	6662.078	115.653	41.561	11.546	18.961
67	3.35	19.301	210.492	6524.609	123.390	39.179	12.083	19.154
68	3.40	19.087	217.620	6381.078	131.434	36.479	12.637	19.314
69	3.45	18.862	224.748	6231.520	139.791	33.452	13.207	19.439
70	3.50	18.625	231.876	6075.977	148.466	30.086	13.793	19.527
71	3.55	18.376	239.004	5914.492	157.465	26.367	14.397	19.576
72	3.60	18.114	246.132	5747.137	166.794	22.288	15.019	19.584
73	3.65	17.839	253.260	5573.961	176.459	17.835	15.658	19.548
74	3.70	17.551	260.388	5395.055	186.465	13.001	16.315	19.466
75	3.75	17.248	267.516	5210.469	196.818	7.767	16.990	19.337
76	3.80	16.930	274.644	5020.305	207.522	2.130	17.683	19.158
77	3.85	16.597	281.772	4824.645	218.585	-3.918	18.395	18.927
78	3.90	16.247	288.900	4623.586	230.013	-10.391	19.126	18.642
79	3.95	15.881	296.028	4417.230	241.810	-17.297	19.875	18.302
80	4.00	15.496	303.156	4205.684	253.981	-24.643	20.645	17.904
81	4.05	15.095	307.476	3990.684	264.121	-31.662	21.434	17.449
82	4.10	14.679	308.988	3774.010	272.056	-38.226	22.242	16.943
83	4.15	14.248	310.500	3555.809	280.137	-45.061	23.071	16.389
84	4.20	13.801	312.012	3336.236	288.367	-52.160	23.920	15.786
85	4.25	13.337	313.524	3115.432	296.747	-59.525	24.790	15.133
86	4.30	12.853	315.036	2893.543	305.276	-67.154	25.680	14.430
87	4.35	12.348	316.548	2670.703	313.959	-75.043	26.592	13.675
88	4.40	11.820	318.060	2447.055	322.795	-83.196	27.525	12.870

89	4.45	11.265	319.572	2222.729	331.785	-91.605	28.479	12.012
90	4.50	10.680	321.084	1997.857	340.930	-100.260	29.456	11.102
91	4.55	10.060	322.596	1772.565	350.233	-109.186	30.454	10.139
92	4.60	9.398	324.108	1545.978	359.694	-118.356	31.475	9.123
93	4.65	8.685	325.620	1321.215	369.314	-127.773	32.518	8.053
94	4.70	7.908	327.132	1095.391	379.094	-137.434	33.584	6.928
95	4.75	7.046	328.644	869.621	389.037	-147.339	34.673	5.748
96	4.80	6.064	330.156	644.013	399.142	-157.482	35.785	4.512
97	4.85	4.889	331.668	419.674	409.411	-167.860	36.921	3.216
98	4.90	3.326	333.180	193.714	419.845	-178.464	38.081	1.847

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89     4.45   11.265   319.572   2222.729   331.785    -91.605   28.479   12.012
90     4.50   10.680   321.084   1997.957   340.930   -100.269   29.456   11.102
91     4.55   10.060   322.596   1772.565   350.233   -109.186   30.454   10.139
92     4.60    9.398   324.108   1546.978   359.694   -118.256   31.475    9.123
93     4.65    8.685   325.620   1321.215   369.314   -127.773   32.518    8.053
94     4.70    7.908   327.132   1095.391   379.094   -137.434   33.584    6.928
95     4.75    7.046   328.644    869.621   389.037   -147.339   34.673    5.748
96     4.80    6.064   330.156    644.013   399.142   -157.482   35.785    4.512
97     4.85    4.889   331.668    418.674   409.411   -167.860   36.921    3.216
98     4.90    3.326   333.180    193.714   419.845   -178.464   38.081    1.847
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                                                    CONE
RADIUS =    1.474 FEET
LENGTH =    5.500 FEET
WEIGHT =  1127.0 LBS
BULK WET DENSITY =   2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  0.30


 IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE
      0.30  0.23  0.28  0.76  1.77  1.67  2.11  2.90  3.40  3.89  3.84  3.89

                 CONDITIONS AT THE END OF SECTION
                                                                  WORK DONE IN SECTION - FOOT POUNDS
  ITERATION PENETRATION   VELOCITY    SHEAR     BODY ENERGY
   SECTION      FEET       FT/SEC  STRENGTH PSF    FT-LBS       STATIC     SEDIMENT     BUOYANT    FORM DRAG
                                                                FORCES     INERTIA      FORCES     FORCES

      1        0.05       15.107       1.080     3997.207       0.000       0.002       0.000       0.001
      2        0.10       15.213       3.240     4053.527       0.001       0.022       0.000       0.006
      3        0.15       15.318       5.400     4109.777       0.004       0.064       0.001       0.017
      4        0.20       15.422       7.560     4165.939       0.012       0.130       0.002       0.033
      5        0.25       15.524       9.720     4221.969       0.025       0.221       0.004       0.056
      6        0.30       15.627      11.880     4277.832       0.048       0.338       0.007       0.084
      7        0.35       15.729      14.040     4333.480       0.079       0.481       0.011       0.119
      8        0.40       15.830      16.200     4388.867       0.121       0.653       0.017       0.161
      9        0.45       15.929      18.360     4443.945       0.176       0.854       0.025       0.209
     10        0.50       16.027      20.520     4498.646       0.245       1.086       0.035       0.265
     11        0.55       16.123      22.680     4552.926       0.331       1.349       0.048       0.327
     12        0.60       16.218      24.840     4606.723       0.435       1.643       0.063       0.397
     13        0.65       16.311      27.000     4659.969       0.559       1.971       0.080       0.475
     14        0.70       16.403      29.160     4712.602       0.704       2.333       0.101       0.560
     15        0.75       16.493      31.320     4764.543       0.873       2.729       0.126       0.654
     16        0.80       16.581      33.480     4815.742       1.066       3.160       0.153       0.755
     17        0.85       16.666      35.640     4866.109       1.286       3.627       0.185       0.865
     18        0.90       16.753      37.800     4915.578       1.535       4.130       0.221       0.983
     19        0.95       16.835      39.960     4964.059       1.813       4.669       0.261       1.109
     20        1.00       16.915      42.120     5011.469       2.123       5.245       0.305       1.245
     21        1.05       16.993      42.948     5057.801       2.392       5.858       0.354       1.389
     22        1.10       17.069      42.444     5103.070       2.601       6.509       0.409       1.541
     23        1.15       17.143      41.940     5147.227       2.814       7.196       0.468       1.703
     24        1.20       17.214      41.436     5190.195       3.033       7.921       0.534       1.873
     25        1.25       17.283      40.932     5231.939       3.257       8.682       0.605       2.053
     26        1.30       17.350      40.428     5272.383       3.485       9.479       0.682       2.241
     27        1.35       17.414      39.924     5311.480       3.716      10.312       0.765       2.439
     28        1.40       17.476      39.420     5349.114       3.952      11.181       0.855       2.646
     29        1.45       17.535      38.916     5385.430       4.190      12.083       0.952       2.861
     30        1.50       17.591      38.412     5420.176       4.431      13.019       1.055       3.086
     31        1.55       17.645      37.908     5453.363       4.674      13.987       1.166       3.320
     32        1.60       17.696      37.404     5484.945       4.920      14.986       1.285       3.562
     33        1.65       17.744      36.900     5514.863       5.166      16.014       1.411       3.813
     34        1.70       17.790      36.396     5542.090       5.414      17.071       1.545       4.073
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35	1.75	17.832	35.892	5569.578	5.663	18.154	1.688	4.341
36	1.80	17.872	35.388	5594.273	5.912	19.262	1.839	4.618
37	1.85	17.908	34.884	5617.152	6.160	20.393	1.999	4.903
38	1.90	17.942	34.380	5638.168	6.409	21.544	2.167	5.195
39	1.95	17.972	33.876	5657.293	6.656	22.715	2.345	5.496
40	2.00	17.999	33.372	5674.484	6.902	23.901	2.533	5.804
41	2.05	18.023	33.300	5689.629	7.240	25.096	2.730	6.119
42	2.10	18.044	33.660	5702.605	7.684	26.295	2.937	6.441
43	2.15	18.061	34.020	5713.371	8.145	27.499	3.155	6.769
44	2.20	18.074	34.380	5721.891	8.624	28.705	3.383	7.103
45	2.25	18.084	34.740	5728.133	9.119	29.910	3.621	7.444
46	2.30	18.091	35.100	5732.066	9.632	31.110	3.871	7.789
47	2.35	18.093	35.460	5733.660	10.164	32.302	4.132	8.139
48	2.40	18.092	35.820	5732.898	10.713	33.482	4.404	8.494
49	2.45	18.087	36.180	5729.758	11.281	34.647	4.688	8.852
50	2.50	14.692	49.536	3780.859	16.099	24.538	4.984	6.080
51	2.55	14.696	51.264	3782.971	17.330	25.274	5.292	6.333
52	2.60	14.696	52.992	3782.508	18.631	25.975	5.613	6.588
53	2.65	14.690	54.720	3779.432	19.992	26.637	5.946	6.844
54	2.70	14.678	56.448	3773.715	21.417	27.253	6.292	7.099
55	2.75	14.662	58.176	3765.328	22.905	27.820	6.652	7.353
56	2.80	14.641	59.904	3754.246	24.459	28.332	7.025	7.606
57	2.85	14.614	61.632	3740.451	26.080	28.785	7.411	7.857
58	2.90	14.581	63.360	3723.936	27.768	29.174	7.812	8.104
59	2.95	14.544	65.088	3704.694	29.527	29.494	8.226	8.349
60	3.00	14.500	66.816	3682.689	31.356	29.739	8.655	8.589
61	3.05	14.448	73.368	3656.008	35.597	29.505	9.099	8.822
62	3.10	14.382	84.744	3622.580	42.437	28.686	9.558	9.041
63	3.15	14.301	96.120	3582.258	49.771	27.615	10.032	9.243
64	3.20	14.206	107.496	3534.918	57.457	26.281	10.521	9.426
65	3.25	14.097	118.872	3480.436	65.554	24.662	11.026	9.586
66	3.30	13.971	130.248	3418.679	74.072	22.740	11.546	9.722
67	3.35	13.829	141.624	3349.609	83.020	20.499	12.083	9.831
68	3.40	13.679	153.000	3273.078	92.406	17.921	12.637	9.911
69	3.45	13.494	164.376	3189.029	102.240	14.986	13.207	9.960
70	3.50	13.298	175.752	3097.400	112.531	11.679	13.793	9.974
71	3.55	13.083	187.128	2998.133	123.287	7.978	14.397	9.952
72	3.60	12.848	198.504	2891.186	134.519	3.868	15.019	9.890
73	3.65	12.591	209.880	2776.525	146.234	-0.669	15.658	9.786
74	3.70	12.310	221.256	2654.131	158.442	-5.651	16.315	9.637
75	3.75	12.004	232.632	2523.992	171.153	-11.096	16.990	9.440
76	3.80	11.672	244.008	2386.111	184.374	-17.020	17.683	9.194
77	3.85	11.310	255.384	2240.496	198.115	-23.440	18.395	8.893
78	3.90	10.916	266.760	2087.168	212.386	-30.372	19.126	8.537
79	3.95	10.467	278.136	1926.157	227.195	-37.833	19.875	8.122
80	4.00	10.017	289.512	1757.504	242.550	-45.839	20.645	7.646
81	4.05	9.509	296.928	1583.559	255.061	-53.309	21.434	7.109
82	4.10	8.962	300.384	1406.732	264.480	-60.068	22.242	6.521
83	4.15	8.370	303.840	1227.137	274.129	-67.139	23.071	5.884
84	4.20	7.724	307.296	1044.886	284.008	-74.526	23.920	5.197
85	4.25	7.003	310.752	860.092	294.123	-82.229	24.790	4.459
86	4.30	6.198	314.208	672.869	304.474	-90.251	25.680	3.669
87	4.35	5.253	317.664	483.329	315.066	-98.594	26.592	2.824
88	4.40	4.080	321.120	291.590	325.900	-107.257	27.525	1.920
89	4.45	2.363	324.576	97.777	336.980	-116.233	28.479	0.936

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IMPACT VELOCITY EQUALS 20.0                                   CONE
SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE                 RADIUS =     1.474 FEET
                                                                                 LENGTH =     5.500 FEET
     0.54  0.67  1.14  2.13  2.34  2.65  2.47  2.34  2.69  2.86  2.92  3.19      WEIGHT =    1127.0 LBS
                                                                                 BULK WET DENSITY =    2.72
                                                                                 DRAG COEFFICIENT =   0.30

           CONDITIONS AT THE END OF SECTION                          WORK DONE IN SECTION - FOOT POUNDS

 ITERATION PENETRATION   VELOCITY   SHEAR       BODY ENERGY        STATIC      SEDIMENT     BUOYANT     FORM DRAG
  SECTION     FEET        FT/SEC  STRENGTH PSF    FT-LBS           FORCES      INERTIA      FORCES      FORCES

     1        0.05       20.080      1.944      7062.309          0.000        0.004        0.000        0.001
     2        0.10       20.160      5.832      7118.586          0.002        0.039        0.000        0.010
     3        0.15       20.239      9.710      7174.766          0.008        0.111        0.001        0.029
     4        0.20       20.318     13.608      7230.727          0.022        0.224        0.002        0.058
     5        0.25       20.397     17.496      7286.405          0.047        0.377        0.004        0.096
     6        0.30       20.474     21.384      7342.125          0.086        0.572        0.007        0.145
     7        0.35       20.551     25.272      7397.295          0.142        0.810        0.011        0.204
     8        0.40       20.627     29.160      7452.516          0.217        1.092        0.017        0.274
     9        0.45       20.702     33.048      7506.238          0.317        1.419        0.025        0.355
    10        0.50       20.776     36.936      7559.548          0.442        1.792        0.035        0.446
    11        0.55       20.848     40.824      7612.773          0.597        2.212        0.048        0.549
    12        0.60       20.919     44.712      7664.926          0.784        2.679        0.063        0.663
    13        0.65       20.989     48.600      7716.191          1.007        3.195        0.080        0.789
    14        0.70       21.058     52.488      7766.477          1.268        3.759        0.101        0.926
    15        0.75       21.124     56.376      7815.150          1.571        4.379        0.126        1.075
    16        0.80       21.190     60.264      7863.435          1.910        5.036        0.153        1.236
    17        0.85       21.252     64.152      7910.016          2.315        5.748        0.185        1.409
    18        0.90       21.312     68.040      7955.558          2.762        6.511        0.221        1.594
    19        0.95       21.371     71.928      7999.245          3.253        7.322        0.261        1.792
    20        1.00       21.427     75.816      8041.273          3.821        8.183        0.305        2.001
    21        1.05       21.480     78.228      8081.578          4.359        9.092        0.354        2.223
    22        1.10       21.532     79.164      8120.145          4.851       10.051        0.409        2.458
    23        1.15       21.580     80.100      8156.671          5.375       11.057        0.468        2.704
    24        1.20       21.626     81.036      8191.672          5.932       12.109        0.534        2.963
    25        1.25       21.669     81.972      8224.441          6.522       13.207        0.605        3.234
    26        1.30       21.710     82.908      8254.982          7.146       14.348        0.682        3.516
    27        1.35       21.747     83.844      8283.504          7.805       15.532        0.765        3.811
    28        1.40       21.781     84.780      8309.617          8.499       16.756        0.855        4.118
    29        1.45       21.812     85.716      8333.316          9.229       18.018        0.952        4.436
    30        1.50       21.840     86.652      8354.516          9.996       19.315        1.055        4.766
    31        1.55       21.865     87.588      8373.133         10.801       20.646        1.166        5.107
    32        1.60       21.885     88.524      8389.070         11.643       22.007        1.285        5.459
    33        1.65       21.902     89.460      8402.246         12.526       23.395        1.411        5.821
    34        1.70       21.916     90.396      8412.586         13.447       24.808        1.545        6.193
    35        1.75       21.926     91.332      8420.004         14.410       26.240        1.688        6.576
    36        1.80       21.931     92.268      8424.422         15.414       27.690        1.839        6.968
    37        1.85       21.933     93.204      8425.781         16.460       29.150        1.999        7.368
    38        1.90       21.931     94.140      8424.004         17.548       30.620        2.167        7.777
    39        1.95       21.924     95.076      8419.020         18.681       32.093        2.345        8.195
    40        2.00       21.914     96.012      8410.773         19.857       33.565        2.533        8.619
    41        2.05       21.898     98.172      8398.969         21.345       35.016        2.730        9.051
    42        2.10       21.878    101.556      8383.254         23.185       36.432        2.937        9.488
    43        2.15       21.852    104.940      8363.551         25.126       37.822        3.155        9.930
    44        2.20       21.821    108.324      8339.777         27.171       39.178        3.383       10.376
    45        2.25       21.784    111.708      8311.852         29.323       40.493        3.621       10.825
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46	2.30	21.742	115.092	8279.688	21.584	41.758	3.871	11.276
47	2.35	21.694	118.476	8243.227	33.958	42.967	4.132	11.729
48	2.40	21.640	121.860	8202.414	36.446	44.113	4.404	12.182
49	2.45	21.581	125.244	8157.176	39.052	45.184	4.688	12.634
50	2.50	18.078	36.540	5724.238	11.868	35.794	4.934	9.215
51	2.55	18.066	36.900	5716.309	12.474	36.917	5.292	9.580
52	2.60	18.049	37.260	5705.969	13.100	38.014	5.613	9.947
53	2.65	18.029	37.620	5693.215	13.745	39.080	5.946	10.316
54	2.70	18.005	37.980	5678.047	14.410	40.113	6.292	10.687
55	2.75	17.977	38.340	5660.465	15.095	41.107	6.652	11.059
56	2.80	17.945	38.700	5640.477	15.802	42.060	7.025	11.431
57	2.85	17.910	39.060	5618.094	16.528	42.968	7.411	11.802
58	2.90	17.870	39.420	5593.336	17.276	43.827	7.812	12.173
59	2.95	17.827	39.780	5566.223	18.046	44.635	8.226	12.542
60	3.00	17.780	40.140	5536.758	18.837	45.384	8.655	12.909
61	3.05	17.728	42.048	5504.371	20.401	45.950	9.099	13.272
62	3.10	17.670	45.504	5468.414	22.814	46.289	9.558	13.630
63	3.15	17.606	48.960	5428.863	25.352	46.509	10.032	13.981
64	3.20	17.535	52.416	5385.723	28.016	46.608	10.521	14.322
65	3.25	17.459	55.872	5333.984	30.812	46.576	11.026	14.655
66	3.30	17.377	59.328	5288.645	33.740	46.404	11.546	14.976
67	3.35	17.288	62.784	5234.707	36.804	46.095	12.083	15.286
68	3.40	17.193	66.240	5177.189	40.007	45.617	12.637	15.582
69	3.45	17.091	69.696	5116.109	43.350	44.991	13.207	15.865
70	3.50	16.983	73.152	5051.490	46.839	44.197	13.793	16.133
71	3.55	16.869	76.608	4982.324	50.472	43.230	14.397	16.384
72	3.60	16.746	80.064	4911.680	54.256	42.089	15.019	16.617
73	3.65	16.617	83.520	4836.566	58.193	40.756	15.658	16.832
74	3.70	16.482	86.976	4758.031	62.284	39.238	16.315	17.028
75	3.75	16.339	90.432	4676.113	66.533	37.521	16.990	17.202
76	3.80	16.190	93.888	4590.863	70.942	35.603	17.683	17.354
77	3.85	16.033	97.344	4502.324	75.515	33.479	18.395	17.483
78	3.90	15.869	100.800	4410.555	80.254	31.143	19.126	17.588
79	3.95	15.697	104.256	4315.602	85.161	28.587	19.875	17.667
80	4.00	15.518	107.712	4217.531	90.240	25.807	20.645	17.719
81	4.05	15.328	113.076	4115.243	97.132	22.274	21.434	17.741
82	4.10	15.127	120.348	4007.809	105.963	17.889	22.242	17.728
83	4.15	14.913	127.620	3895.129	115.140	13.135	23.071	17.673
84	4.20	14.685	134.892	3777.203	124.669	8.001	23.920	17.576
85	4.25	14.444	142.164	3654.391	134.557	2.478	24.790	17.435
86	4.30	14.189	149.436	3526.426	144.807	-3.441	25.680	17.248
87	4.35	13.919	156.708	3393.500	155.426	-9.766	26.592	17.012
88	4.40	13.634	163.980	3255.674	166.421	-16.507	27.525	16.727
89	4.45	13.332	171.252	3113.020	177.797	-23.669	28.479	16.390
90	4.50	13.012	178.524	2965.609	189.559	-31.264	29.456	15.999
91	4.55	12.674	185.796	2813.525	201.714	-39.297	30.454	15.552
92	4.60	12.316	193.068	2656.852	214.266	-47.776	31.475	15.048
93	4.65	11.937	200.340	2495.672	227.223	-56.708	32.518	14.485
94	4.70	11.534	207.612	2330.078	240.589	-66.095	33.584	13.861
95	4.75	11.106	214.884	2160.156	254.372	-75.953	34.673	13.174
96	4.80	10.648	222.156	1985.002	268.575	-86.282	35.785	12.422
97	4.85	10.159	229.428	1807.707	283.206	-97.089	36.921	11.604
98	4.90	9.633	236.700	1625.767	298.270	-108.380	38.081	10.719
99	4.95	9.064	243.972	1439.078	313.772	-120.162	39.265	9.763
100	5.00	8.444	251.244	1248.938	329.718	-132.439	40.473	8.736
101	5.05	7.771	254.520	1057.831	340.765	-142.659	41.705	7.645
102	5.10	7.042	253.800	869.638	346.597	-150.526	42.963	6.508
103	5.15	6.237	253.080	681.423	352.458	-158.472	44.245	5.333
104	5.20	5.323	252.360	496.244	358.346	-166.492	45.553	4.121
105	5.25	4.228	251.640	313.157	364.262	-174.579	46.886	2.868
106	5.30	2.749	250.920	132.219	370.204	-182.721	48.245	1.560

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A rational method is presented to predict the penetration of free-falling objects into deep-sea sediments by combining proven empirical theories from the field of soil mechanics with known hydrodynamic phenomena. The impact velocity of the object and the shear strength profile and density of the sediment are assumed to be known. The penetration problem was solved through the use of a computer by equating the work done during penetration to the energy of the object falling through air and impacting onto a modeled deep-sea sediment. The objects were simple geometric shapes ranging in weight from 500 to more than 1,000 pounds. The impact velocities ranged from zero to twenty feet-per-second. The results are compared with full scale tests and recommendations are made to extend the method to a water-sediment interface. The method successfully predicts the penetration of objects into weak, saturated, sediments within the accuracy of the state-of-the-art techniques for measuring the sediment mechanical properties. The impact duration time was observed to be relatively constant and independent of object velocity, shape, and weight implying that it may be a unique property of the dynamic behavior of a sediment type.

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